Defence Research and Development Canada | Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Literature and Product Review of Visual Analytics for Maritime Awareness

Michael Davenport
Salience Analytics Inc.

Prépared by:

MacDonald Dettwiler and Associates Ltd.
13800 Commerce Parkway
Richmond, BC, Canada V6V 2J3

PWGSC Contract Title: Visual Analytics State-of-the-Art Study and Requirements Identification for Maritime Applications
PWGSC Contract No.: 92075/NP
DRDC Project Manager: Ms. Valérie Lavigne, (418) 844-4000 Ext.: 4114
DRDC Scientific Authority: Ms. Valérie Lavigne, (418) 844-4000 Ext.: 4114
Project Period: June 2009 – Oct 2009
MDA Document Number: RX-RP-52-8724

Defence R&D Canada – Valcartier
Contract Report
DRDC Valcartier CR 2009-228
October 2009

Canada

Literature and Product Review of Visual Analytics for Maritime Awareness

October 28, 2009

DRDC Valcartier CR 2009-228

Michael Davenport
Salience Analytics Inc.

MacDonald Dettwiler and Associates Ltd.
13800 Commerce Parkway
Richmond, BC, Canada
V6V 2J3

PWGSC Contract Title:	Visual Analytics State-of-the-Art Study and Requirements Identification for Maritime Applications
PWGSC Contract No.:	92075/NP
DRDC Document Number:	CR 2009-228
DRDC Project Manager:	Ms. Valérie Lavigne, (418) 844-4000
DRDC Scientific Authority:	Ms. Valérie Lavigne, (418) 844-4000
Project Period:	June 2009 – Oct 2009
MDA Document Number:	RX-RP-52-8724

Prepared By:	Mike Davenport Principal Investigator Salience Analytics Inc.	_____ (Signature and Date)
Reviewed by:	Harold Zwick R&D Manager MacDonald Dettwiler and Associates Ltd.	_____
Approved by:	Melanie Dutkiewicz Project Manager MacDonald Dettwiler and Associates Ltd.	_____

CHANGE RECORD

ISSUE	DATE	PAGE(S)	DESCRIPTION
1/0	Oct. 28, 2009	All	First Issue

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

This is a study of the state-of-the-art in Visual Analytics (VA) technologies that might support the maintenance of the Recognized Maritime Picture (RMP). It begins with an analysis of the term "Visual Analytics," including what qualifies and does not qualify under that term, and proposes a 4-point checklist of required elements. It reviews what interaction patterns are typical in VA and what topics need to be visualized for the RMP, and thus establishes a list of required tool capabilities. Links are then provided to approximately 70 papers that address these requirements. Global VA researchers, research groups, journals, and conferences are summarized. Fifteen VA products that are particularly relevant to the identified requirements are tabulated. An annotated bibliography, attached as an appendix, lists and provides an educated assessment of 146 relevant papers, websites, and product brochures.

RÉSUMÉ

Ceci est une étude de l'état de l'art des technologies d'Analytique Visuelle (AV) qui seraient susceptibles de soutenir la mise à jour du Tableau de la Situation Maritime (TSM). Elle débute avec une analyse du terme « Analytique Visuelle », incluant ce qui se qualifie et ne se qualifie pas sous cette définition, et propose une liste de contrôle de quatre points des éléments requis. Elle passe en revue les modèles d'interaction typiques en AV et les sujets qui doivent être visualisés pour le TSM et établit ainsi une liste des fonctionalités requises pour l'outil. Ensuite, des liens vers environ 70 articles qui addressent ces exigences sont fournis. Un résumé des chercheurs en AV, des groupes de recherche, des journaux et des conférences est aussi donné. Quinze produits d'Analytique Visuelle qui sont particulièrement pertinents en regard des exigences identifiées sont colligés. Finalement, une bibliographie annotée énumérant et fournissant une évaluation de 146 articles, sites internet et brochures de produits se trouve en annexe.

EXECUTIVE SUMMARY

This report describes a study of state-of-the-art Visual Analytics (VA) approaches and technologies that could be used to improve the development of, and interaction with, the Recognized Maritime Picture (RMP). Given a tendency for the phrase "Visual Analytics" to be used quite liberally, Section 2 first examines what the term means and does not mean and concludes that, to be VA, a tool must include:

- **Visualization:** Use complex and abstract depictions
- **Interaction:** Allow rich interactions with the visualization
- **Exploration:** Facilitate the discovery of new information
- **Analysis:** Encourage users to assemble evidence into a "story"

Section 3 then characterizes the global VA research community by introducing nine key researchers and technology leaders and the institutions that they work with. This includes an overview of the Visual Analytics Consortium in North America, and parallel developments in Europe.

Section 4 is the main Literature Review. The first subsection lists nine journals and conferences that serve the VA research community, noting in particular the importance of IEEE's Visual Analytics Science and Technology (VAST) conference. Because many important papers are self-published or released as preprints on the web, Section 4.1.4 also lists those research institutes that maintain home pages with important VA content. Based on separate consultations with RMP experts, Section 4.2 identifies the following VA capabilities that are of particular interest:

- Geo-spatial-temporal situation awareness
- Geo-spatial-temporal data mining
- Geo-spatial-temporal uncertainty representation
- Geo-temporal coverage analysis
- Predictions and what-if analysis
- Sensor and network monitoring
- Social network analysis
- Collaboration
- Textual and news-feed exploration
- User interfaces and usability for Visual Analytics
- Visual Analytics design principles

Section 4.3 identifies and briefly introduces approximately 70 publications that address these topics.

Section 5 then reviews fifteen VA products that are already available with some or all of these capabilities. A table for each product provides a screen-grab or image, a brief review of its capabilities and limitations, an assessment of whether it really is Visual Analytics (based on the above four requirements), and links to further information. Video clips are attached where possible, because they provide a better description of user-interactions that are very important for Visual Analytics.

Appendix B is an annotated bibliography of the papers, websites, and products cited in this paper. Each listing provides standard citation information, web links if available, and an informed assessment of the relevance and value of the item cited. Where possible, copies of the cited documents and videos have been delivered as digital files with this report, and those files are referenced by name in the bibliography. The EndNote database used to generate the bibliography has also been delivered.

RAPPORT SOMMAIRE

Ce rapport décrit une étude sur l'état de l'art des technologies et approches en Analytique Visuelle (AV) qui pourraient être utilisées pour améliorer le développement du Tableau de la Situation Maritime (TSM) et l'interaction avec ce dernier. Considérant le fait que l'expression « Analytique Visuelle » est employée assez libéralement, la Section 2 examine ce que l'expression signifie et ne signifie pas et conclut que, pour être considéré AV, un outil doit comprendre :

- **Visualisation** : Employer des représentations complexes et abstraites
- **Interaction** : Permettre des interactions riches avec la visualisation
- **Exploration** : Faciliter la découverte d'information nouvelle
- **Analyse** : Encourager les utilisateurs à réunir les évidences pour en former une « histoire »

La Section 3 caractérise la communauté de la recherche globale en AV en présentant neuf chercheurs importants et les institutions auxquelles ils sont affiliés. Ceci inclut une vue d'ensemble du Consortium en Analytique Visuelle d'Amérique du Nord et des développements parallèles en Europe.

La Section 4 contient la revue de la littérature. La première sous-section énumère neuf journaux et conférences visant la communauté de la recherche en AV, soulignant en particulier l'importance de la conférence Visual Analytics Science and Technology (VAST) de IEEE. Puisque beaucoup d'articles importants sont publiés indépendamment ou rendus disponibles sous forme de prétirages sur internet, la Section 4.1.4 énumère également ces instituts de recherche qui maintiennent des pages avec du contenu important en AV. Suite à des consultations indépendantes avec des experts en matière de TSM, la section 4.2 identifie les possibilités suivantes en AV qui présentent un intérêt particulier :

- Éveil situationnel géo-spatiale-temporelle
- Exploitation de données géo-spatiales-temporelles
- Représentation de l'incertitude géo-spatiale-temporelle
- Analyse de la couverture géo-temporelle
- Prévisions et analyse par simulation
- Surveillance à l'aide de capteurs et de réseaux
- Analyse de réseaux sociaux
- Collaboration
- Exploration de textes et de nouvelles en continu
- Interfaces utilisateurs et utilisabilité pour l'analytique visuelle
- Principes de conception de l'analytique visuelle

La Section 4.3 identifie et présente brièvement environ 70 publications qui abordent ces sujets.

La Section 5 passe en revue quinze produits d'AV qui sont déjà disponibles et qui possèdent certaines ou toutes ces fonctionnalités. Pour chacun de ces produits, est fourni un tableau contenant une capture d'écran ou image, une critique brève de ses possibilités et limitations, une évaluation de sa conformance à l'Analytique Visuelle (basée sur les quatre critères ci-haut) et des liens vers de l'information supplémentaire. Lorsque cela s'avère possible, des extraits vidéo sont ajoutés car ils fournissent une meilleure idée des interactions utilisateur qui sont très importantes pour l'Analytique Visuelle.

L'annexe B est une bibliographie annotée des articles, sites internet, et produits mentionnés dans ce document. Chaque entrée est composée de la référence, du lien internet si disponible et d'une évaluation de la pertinence et de la valeur de la dite entrée. Lorsque cela était possible, des copies numériques des documents et vidéos mentionnés ont été fournies avec ce rapport. Ces fichiers sont identifiés par leur noms dans la bibliographie. La base de données EndNote employée pour produire la bibliographie a été également fournie.

1 INTRODUCTION

This document identifies and characterizes "Visual Analytics" technologies and products relevant to maritime domain awareness in the Canadian Forces regional joint operations centres (RJOCs). It is one of two deliverables (the second deliverable is [31]) from the Visual Analytics for Maritime Awareness (VAMA) contract.

Sections 1.1 and 1.2, which are repeated in both documents, give a brief overview of the context and scope of the contract.

Task 1 investigations, described in Sections 2 through 5, include:

- A discussion of what the term "Visual Analytics" means, some of the challenges associated with that term, and a taxonomy of visual analytics technologies and techniques (Section 2).
- An overview of the emerging Visual Analytics research community (Section 3).
- A guide to the Annotated Bibliography and overview of the academic papers that were found (Section 4).
- A review of the Visual Analytics products that were found (Section 5).
- The Annotated Bibliography itself (Appendix B).

1.1 Motivation

The Canadian Forces (CF) has a mandate to be aware of all that is happening (i.e. all "situational facts") in Canada's maritime approaches. It is based on the need to protect Canada from attack, defend Canada's sovereignty, detect illegal activities, and support search and rescue activities. The mandate became more challenging in the past decade, as commercial shipping became a potential threat.

Regional Joint Operations Centres (RJOCs) in Halifax and Esquimalt maintain 24/7 watch over Canada's three oceans in support of the mandate. They do this by extracting situational facts from a variety of sensor data streams and analysis tools that have been documented elsewhere (e.g. [33]). The main challenges facing the RJOCs are not a lack of data – in some ways the RJOCs are drowning in data – but rather:

- The data has often been degraded by ambiguities and data-entry errors, requiring operators to spend large amounts of time cleaning up the data to reveal the underlying facts. Efforts are currently being made by DRDC Centre for Operational Research and Analysis (CORA) to address this with the Attribute Correction Engine (ACE) and the RMP Analysis Toolset (RAT).
- The data has too often been delivered to the operators as individual dots on screens, rather than being first resolved into tracks. This was recently addressed by the Multi-Sensor Integration within a Common Operating Environment (MUSIC) Technology Demonstration Program led by DRDC Atlantic.
- A huge fraction of the information presented to the operators is mundane, and no attempt is made to draw attention to the non-mundane. Automated knowledge management solutions to this are being addressed in the Automated Reasoning for Maritime Anomaly Detection (ARMAD) contract at DRDC Valcartier. The Maritime Domain Analysis through Collaboration and Interactive Visualization (MDACIV) project at DRDC Valcartier is exploring user-interactive solutions.

The Visual Analytics for Maritime Awareness (VAMA) contract is searching for state-of-the-art visual analytics approaches and technologies to support the visualization, interaction with, and analysis of the RMP. The study includes an assessment of the technologies, a survey of the scientific literature, and an analysis of user requirements.

Previous DRDC studies have documented RJOC activities (e.g. [29], [33]) potential requirements ([27]; [113]), and relevant visualization technologies ([32]; [28]). These studies highlighted challenges such as the following for both automated and human detectors:

- Contact reports typically have low cadence (i.e. are infrequent);
- Some information sources (the cleanest ones) are voluntary and thus spoofable, though there are few scenarios where spoofing would be advantageous to an attacker;
- Some parts of Canada's area of responsibility are poorly covered by sensors;
- Some important information streams are not available to the RJOCs due to legal firewalls.

1.2 VAMA Contract Scope

The scope of the VAMA contract is summarized in Figure 1-1. Task 1 (recorded in this document) is a literature study and product review of state-of-the-art visual analytics

technology, recorded in an annotated bibliography. Task 2 is an analysis of how visual analytics could help the RJOCs achieve their operational objectives.

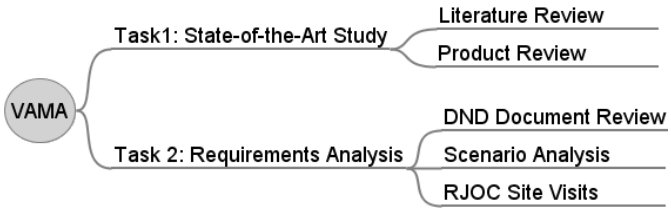


Figure 1-1 VAMA will lay the groundwork for Visual Analytics prototype development
The VAMA contract includes a literature review, product review, and requirements analysis.

THIS PAGE INTENTIONALLY LEFT BLANK

2 DEFINING VISUAL ANALYTICS

Researchers agree with the following definition of Visual Analytics from *Illuminating the Path*, and quote it frequently:

> "Visual Analytics is the science of analytical reasoning facilitated by interactive visual interfaces." [ref [131], pg 4] (2-1)

The following subsections refine this definition by discussing the normal objectives, typical behaviour, and minimal capabilities of interactive visual interfaces that are truly "Visual Analytics" systems, and then proposing a taxonomy of the field.

2.1 Objectives

Thomas summarizes the goal of Visual Analytics interfaces as follows:

> "The goal of visual analytics is to facilitate this analytical reasoning process through the creation of software that maximizes human capacity to perceive, understand, and reason about complex and dynamic data and situations. It must build upon an understanding of the reasoning process, as well as an understanding of underlying cognitive and perceptual principles, to provide mission-appropriate interactions that allow analysts to have a true discourse with their information. The goal is to facilitate high-quality human judgment with a limited investment of the analysts' time." [ref [131], pg 6]

Note the following features in this statement:

- The software reaches out to the users, seeking a good "impedance match" between the data space and the human mind.
- Interactions are understood to be mission-specific.
- Interfaces are based on scientific models of human cognition.

2.2 Common Visual Analytic Patterns

Typical activities and applications of Visual Analytics are [refs [61], [130]]:

- Synthesizing information into knowledge
- Deriving insight from massive, dynamic, and often conflicting data
- Detecting the expected
- Discovering the unexpected
- Providing timely, defensible, and understandable assessments
- Communicating assessments effectively for action

Schneiderman [ref [118]] observed that interactive visualization tools always support the following sequence of activities:

1. Overview of the data space
2. Zoom
3. Filter
4. Details on demand (drill-down)
5. Relate (view links)
6. Show history
7. Extract information

Keim [77] suggests that the Visual Analytics has the following slightly different sequence:

1. Analyse First
2. Show what is Important
3. Zoom
4. Filter
5. Analyse Further
6. Details on Demand

Riveiro [107] finds the “foraging loop” [131] a more appropriate pattern for describing visual analytic sequencing. Her model (see Figure 2-1) suggests the following sequence:

1. Frame the data
2. Question the frame
3. a) Elaborate (add detail to) the frame or
   b) Discard and re-frame

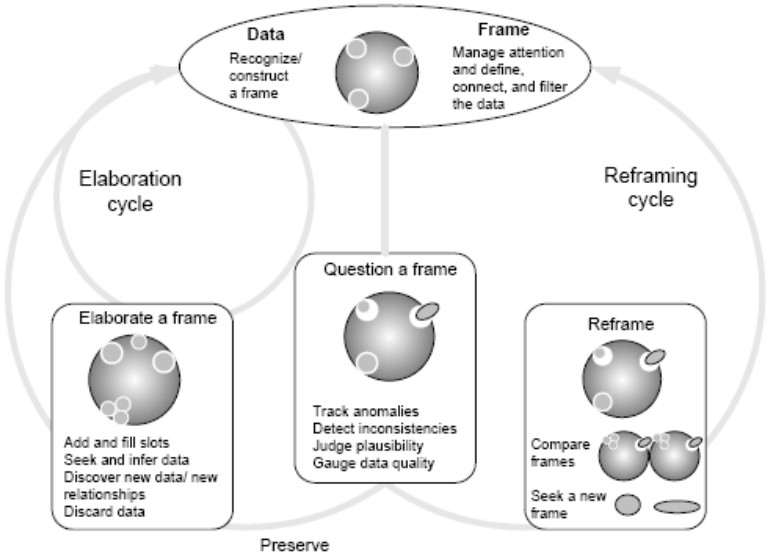


Figure 2-1 Visual Analytics as a Framing and Elaboration Cycle.
Riveiro proposes a dual-cycle visual analytics cycle, focused on framing the data. If the frame is working, an elaboration cycle is used to clean up what is in the frame and insert more insights. If the frame is not working, a new frame is sought so the data can be reframed.

The published videos of Jigsaw [125], Starlight [101], and In-Spire [100] are characterized by the following sequence:

1. Query or visualize the evidence (in multiple visual domains)
2. Find patterns and filter the evidence
3. Visualize what links to the evidence
4. Find patterns and filter the links
5. Follow the links to new evidence
6. Repeat (1-5)

2.3 Narrowing the Definition

Because Visual Analytics is enjoying a surge of attention from researchers, there is a risk that the meaning of the term will be diluted through over-use. A visualization paper by Bak for example [9] is falsely labeled as visual analytics. This section thus proposes ways to tighten up definition (2-1).

Jim Thomas [130] narrows the definition of Visual Analytics by noting that the following system features that are not (by themselves) indicative of Visual Analytics:

- Large graph structures with no labels
- Heat maps with no labels
- Search and retrieval systems

- Charts with no interaction
- Images with no semantic interpretation
- Stand alone images that do not tell a story

It is thus not enough to have a visualization strategy; the tool must provide *meaningful interaction* with the visualization, that leads to a labeled view that tells a story. And the tool must *facilitate the discovery* of the story – thus Photoshop, though capable of presenting a complex visual story, is not a Visual Analytics tool.

We thus amplify the definition (2-1) of Visual Analytics tools by requiring that each must be:

- **A Visualization tool:** the tool must depict complex, abstract, or voluminous information using substantially sophisticated or abstract views. (2-2)
- **An Interactive tool:** users must be able to modify the visualization, filter data, assess hypotheses, infer meaning, and test the truth. (2-3)
- **An Exploratory tool:** the tool must facilitate the discovery of unexpected or hidden meanings. (2-4)
- **An Analytical tool:** users must be able to assemble evidence, record ideas, and build an underlying "story" that gives meaning to the data. (2-5)
- **A Scientific tool:** the tool must be based on scientific cognitive and perceptual models, and amenable to scientific investigation. (2-6)

2.3.1 Alternative Terminology

Caution must be used with the term "Visual Analytics" because it is copyrighted [ref [137]]. Thus the National Visualization and Analytics Center (NVAC) uses the phrase "visualization and analytics" rather than "visual analytics." The term "Visual Analytics" continues to be widely used, however, perhaps because of *Illuminating the Path* [131].

2.4 Visual Analytics Taxonomies and Typologies

Experts in the science of classification [8] distinguish between the "taxonomies" and "typologies" as follows:

- **Typology:** a classification procedure in which only the concepts are classified. Thus each item has multiple characteristics that define its classification.
- **Taxonomy:** a classification procedure in which only empirical entities are classified. Thus each item belongs to exactly one class.

There is no reason to believe that a true taxonomy of Visual Analytics is possible or even desirable, because the topic is fundamentally aimed at combining a variety of views, bringing together many different types of data, and addressing multiple operational goals.

Some example typologies from Jim Thomas (Figure 2-2 and Figure 2-3) and Georgia Tech (Figure 2-4) are shown below. The wording in Figure 2-2 has been changed as follows:

- Descriptions of "Goals" have all been changed to verb form
- "Defraud" and "Deceive" have been combined
- "Collaborate" has been inserted
- The "Uncertainty / Imprecision" data type has been inserted

The Starlight tool, one of the first Visual Analytics applications to be developed, has at its core a useful taxonomy of information *shapes*, as shown in Figure 2-5. By making the taxonomy small, while still supporting all types of relationship, the designers empower Starlight to display almost any type of information relationship using only six types of display axis.

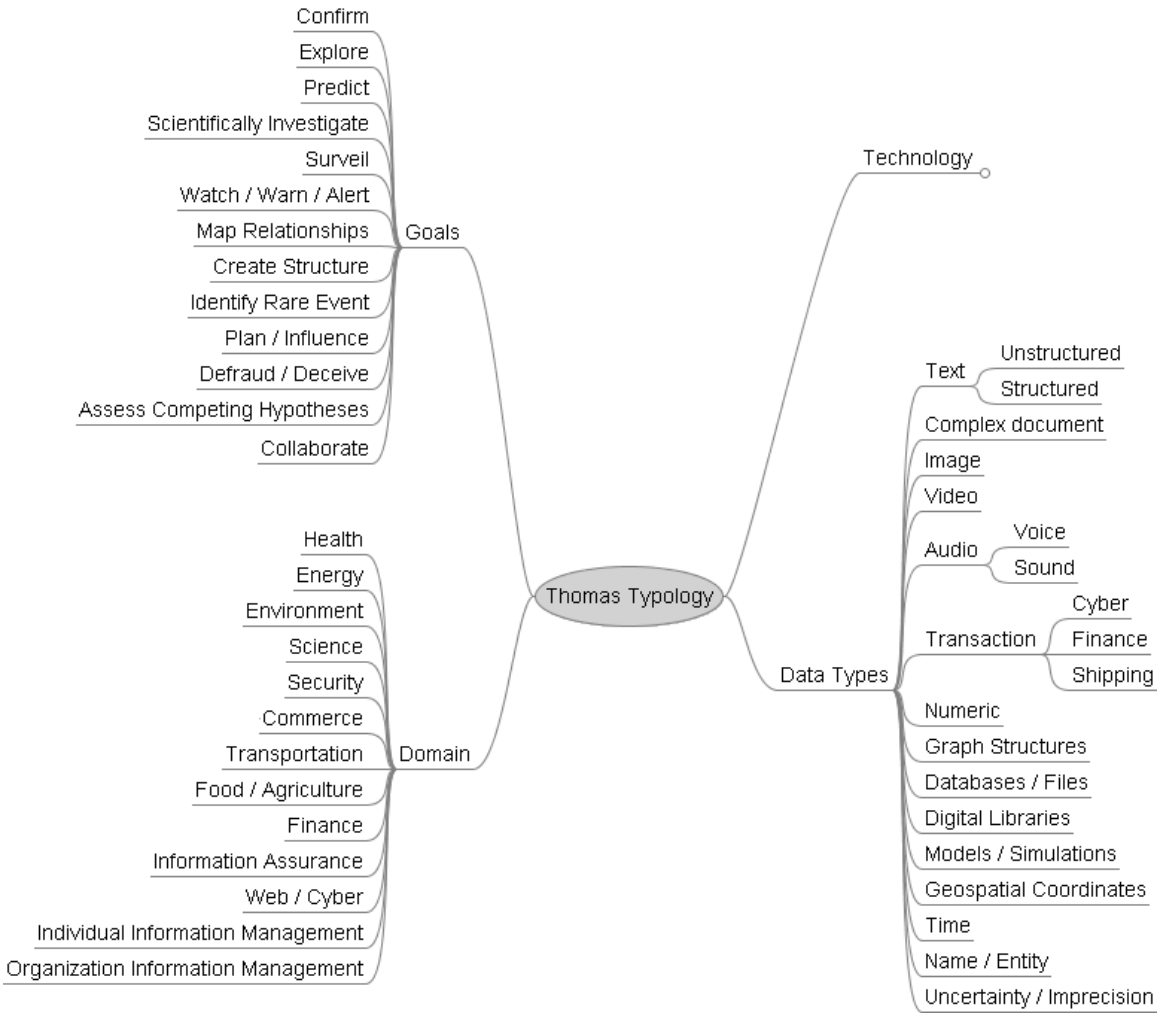


Figure 2-2 Jim Thomas's Typology of Visual Analytics, Goals, Domains, and Data Types
Jim Thomas, a central figure in Visual Analytics development, proposed this typology (he called it a "taxonomy") based on four characteristics that each application has: data types, analysis goals, application domain, and technology employed [based on [129]]. The "technology" branch is expanded in Figure 2-3.

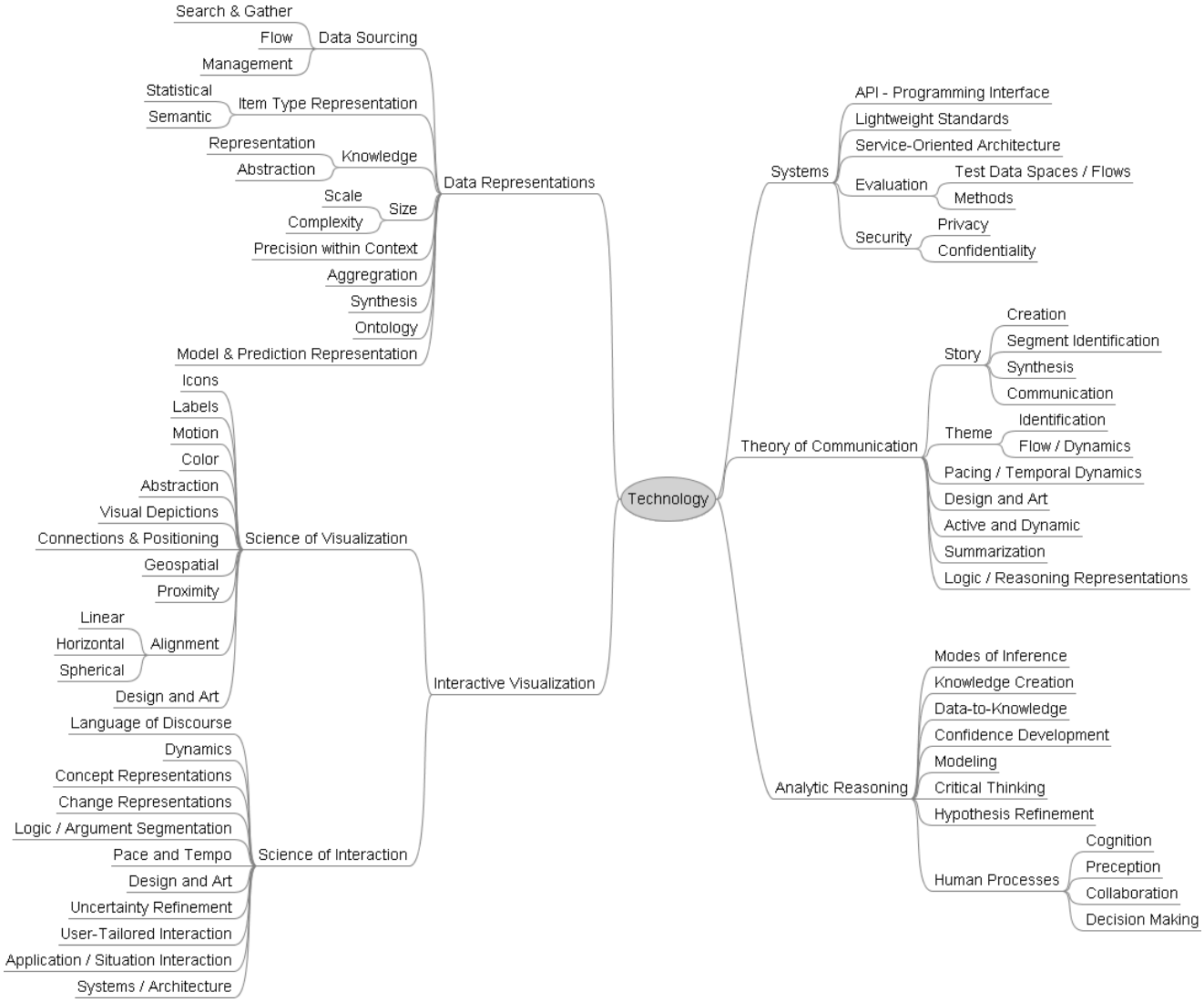


Figure 2-3 Jim Thomas's Typology of Visual Analytics Technologies

This completes the typology introduced in Figure 1-1. [based on [129]].

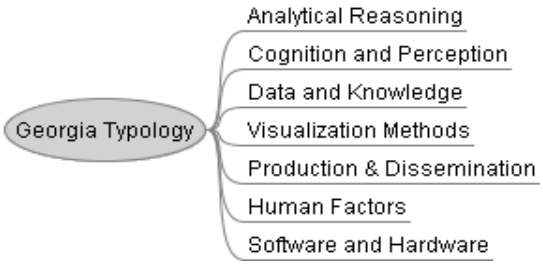


Figure 2-4 Georgia Tech Typology of Visual Analytics Technologies

Georgia Tech uses this typology to organize their teaching material. [based on [48]]

Relationship Type:	General Similarity	Explicit Reference	Field/Value Co-occurrence	Parent/Child	Spatial	Temporal
Model Type:	*Vector-space*	*Network*	*Multidimensional Index*	*Hierarchical*	*Spatial*	*Ordinal Index*
Examples:	*Reports, articles, DB records*	*References & citations, hyperlinks*	*DB records, document metadata*	*File paths, taxonomies, IP addresses*	*Geolocations, CAD models*	*Event descriptions*

Figure 2-5 Starlight Taxonomy of Information Relationships

Starlight achieves very flexible information display by reducing all types of information relationships to these six classes. Types of relationship not shown here (e.g. similarity of meaning in text) can be displayed if they can be reduced to one of these classes (e.g. a vector –space that is representative of textual meaning). (from Figure 2-5 of [28]).

3 VISUAL ANALYTICS RESEARCH COMMUNITY

The following sections describe key agencies and departments that are coordinating and implementing Visual Analytics research, including:

- Individuals who are influential in the field, or strategic to the interests of DRDC (Section 3.1)
- Coordinating agencies and collaborative structures (Section 3.2)

3.1 Key People

This section gives a brief introduction to some of the most influential individuals in the Visual Analytics (VA) research community.

3.1.1 Dr. Jim Thomas

Affiliation:

- Laboratory Fellow at Pacific Northwest National Laboratory (PNNL).

Notable For:

- Founding Director, National Visual and Analytics Center (NVAC) (resigned August 2009).
- Co-wrote "Illuminating the Path" [131] thus setting the agenda for visual analytics research.
- Set up the network of centers of excellence.
- Knows everyone in the VA community.
- PNNL is notable for Starlight and InSpire.

3.1.2 Dr. Joe Kielman

Affiliation:

- Department of Homeland Security (DHS).
- Director, Research Futures.
- Science advisor in the office of the Under Secretary for Science and Technology.

Notable For:

- Single most important US customer representative.
- He sees the objective of Visual Analytics as 'to seek ways to deliver "designer information"—up-to-date, customized or tailored knowledge delivered just as needed.' [78]

3.1.3 Prof. David Ebert

Affiliation:

- Director, Purdue University Regional Visualization and Analytics Center (PURVAC).
- PURPL : Purdue University Rendering and Perceptualization Lab.

Research Focus:

- Novel visualization techniques, visual analytics, volume rendering, information visualization, perceptually-based visualization, illustrative visualization, and procedural abstraction of complex, massive data.

Notable For:

- Purdue is the senior and managing lab in Visual Analytics for Command, Control, and INteroperability Environments (VACCINE).

3.1.4 Prof. Brian Fisher

Affiliation:

- Associate Professor, Simon Fraser University (SFU) and University of British Columbia (UBC).
- Director, SFU Spatial Cognition and Interactive Expertise in Natural and Computational Environments (SCIENCE Lab).
- Associate Director, SFU Visual Analytics Research Lab (VAR Lab).

Research Focus:

- Cognitive and social science-based approaches to development and evaluation of analytics systems and processes.

Notable For:

- The leading Canadian academic in visual analytics.

3.1.5 Prof. John Stasco

Affiliation:

- Director of the Georgia Tech component of the Southeastern Regional Visualization and Analytics Center (SRVAC).
- Director of the Information Interfaces Research Group.

Research Focus:

- central focus of a number of our projects is the creation of information visualization and visual analytics tools to help people understand and analyze large data sets.

Notable For:

- Georgia Tech is notable for Jigsaw and the Global Terrorism Database.

3.1.6 Prof. Haesun Park

Affiliation:

- Director of Foundations of Data and Visual Analytics (FODAVA).
- Professor and Associate Chair, Georgia Tech.

Research Focus:

- Numerical Algorithms, Data and Visual Analytics, Bioinformatics, Text Analysis.

Notable For:

- Has not published any Visual Analytics papers.

3.1.7 Dr. Richard May

Affiliation:

- Director, National Visual and Analytics Center (NVAC) (as of August 2009).
- Previous co-chair IEEE Visual Analytics Science and Technology (VAST) conference.

Research Focus:

- Designing new technologies and protocols to generate and interact with complex, massive data sets.
- He has conducted research in video and image processing, information visualization, virtual and mixed reality and visual analytics.

3.1.8 Drs. Gennady and Natalia Andrienko

Affiliation:

- (both) Research fellows, Fraunhofer IAIS , Germany.
- (G) Chair of the Commission on GeoVisualization of the International Cartographic Association:

Research Focus:

- Visualisation of spatial and spatio-temporal data as a tool for visual analytics, exploratory data analysis, problem solving, and decision making.
- Co-editors of the Geovisualization of Dynamics, Movement and Change special issue of *Information Visualization.*
- Co-authors of *Exploratory Analysis of Spatial and Temporal Data*, (Springer-Verlag, 2005).

3.2 Coordinating Agencies and Collaborations

The following key agencies and coordinating bodies in Visual Analytics are described in this subsection:

- US Department of Homeland Security (DHS) Section 3.2.1.
- National Visual and Analytics Centre (NVAC) Section 3.2.2.
- The Visual Analytics Consortium (VAC) Section 3.2.3.
- Visual Analytics for Command, Control, and INteroperability Environments (VACCINE) and Foundations on Data Analysis and Visual Analytics (FODAVA) Section 3.2.4.
- Visual Analytics organizations in Europe: Section 3.2.5.

3.2.1 US Department of Homeland Security

The Research and Development agenda for Visual Analytics was, from the beginning, motivated by the following seven strategic goals and objectives of the US Department of Homeland Defense (DHS): awareness, prevention, protection, response, recovery, service (to normal activities), and organizational excellence (within the DHS) (page 3 of [131]). Five years later, the DHS remains the principal funding source for the various centers of excellence.

Fisher (pg 2 of [41]) lists the following DHS presidential directives (paraphrased here based on [56]) as being of direct relevance to visual analytics:

3: Create a Homeland Security Advisory System to evaluate and report on the current risk of terrorist acts.

5: Provide a single, comprehensive national incident management system for the prevention, preparation, response, and recovery from terrorist attacks, major disasters, and other emergencies.

7: Identify and prioritize critical infrastructure and protect them from terrorist attacks.

8: Establish standard and comprehensive approach to national planning so as to be prepared to prevent and respond to threatened or actual domestic terrorist attacks, major disasters, and other emergencies. .

9: Defend the agriculture and food system against terrorist attacks, major disasters, and other emergencies.

10: Provide support for threat awareness, prevention, protection, surveillance, detection, response and recovery against the biological weapons threat.

21: Be prepared to respond to the public health and medical needs of the American people in the case of a catastrophic health event through continual and timely flow of information.

23: The National Cyber Security Initiative, which presumably (this topic is not addressed on the website) searches for vulnerabilities in the American computer network infrastructure, detects incursions, and supports network defense activities in response to an attack.

To achieve this mandate, the DHS budget has two line-items specifically for Visual Analytics through VACCINE and FODAVA (Section 3.2.4):

- Approximately $4.5M per year for basic future research (shared with physics-based simulations as shown in Figure 3-1).
- Approximately $3M per year funding to university Centers of Excellence for Command, Control, and Interoperability.

Other DHS funding mechanisms, such as "International and Interagency Programs" (pg 161 of [35]) are also available. As a major funding agency, DHS has a strong influence on how the visual analytics community is organized, and on what topics they do research. Thus for example the re-organizations listed in Sections 3.2.3 and 3.2.4 were influenced by DHS expectations and preferences.

As discussed in Section 3.2.4, the National Science Foundation now also provides funding for visual analytics.

PPA	Thrust Area	Program	FY 08 (RE) ($000)	FY09 (PB) ($000)	FY10 (Plan) ($000)	FY11 (Plan) ($000)	FY12 (Plan) ($000)	FY13 (Plan) ($000)
Control & Interoperability	Interoperability and Compatibility	OIC	10,290	11,084	8,270	6,477	4,671	7,144
	Cyber Security	Cyber Security Research Tools and Techniques	7,160	6,971	6,000	6,400	7,000	7,200
		Information Infrastructure Security	9,880	11,181	8,577	8,573	6,152	7,012
		Next Generation Technologies	2,841	0	700	800	2,975	3,134
	Basic Future Research	Visual Analytics and Physics-based Simulation	4,235	4,536	4,744	4,813	5,028	5,142

Figure 3-1 Homeland Security Budget Line Item for University Visual Analytic Research
Basic future research in visual analytics is funded under the Command, Control, & Interoperability (CCI) segment of the DHS Science and Technology budget. Shown here is an excerpt from [35].

3.2.2 National Visualization and Analytics Center

The National Visualization and Analytics Center (NVAC) was established in 2004 by the Department of Homeland Security to develop the tools to identify and prevent terrorist attacks. NVAC is part of Pacific Northwest National Labs (PNNL) and is located in Richland Washington. The NVAC assembled a multidisciplinary panel representing government, academia and industry to develop a Research and Development Agenda [131] to define the directions and priorities for future visual analytics developments. NVAC inherited two visual analytic tools, Starlight and In-Spire, from Pacific PNNL and immediately started developing more.

The NVAC [92] lists the following research areas that they are currently pursuing:

- Large Scale Graph Perception
- Analytic Discourse and Scenario Understanding
- Mobile Visualization Platforms
- Statistical and semantic information representations and transformations
- High dimensional information synthesis
- Visualization and Interaction paradigms
- Temporal and Spatial visual analytics
- Information packaging and dissemination
- Calibration and Validation of Information
- Collaboration technologies for distributed visual analytics
- Architectures for Information-Processing and visual analytics

3.2.3 VAC Consortium

Once the NVAC was established, it immediately started encouraging the establishment of smaller “regional” Visual Analytics Centers (VACs) and Centers of Excellence (COEs). Principal members of the resulting consortium of academic centers are shown in Figure 3-2.

Under the leadership of the NVAC, a consortium of VA capability suppliers (including industry members) and VA capability users (both government and industry) was formed. The group meets at least twice a year to “promote a high-level of information exchange between NVAC/RVAC science and technologies and all suppliers of information and visual analytics and technology solutions” [96].

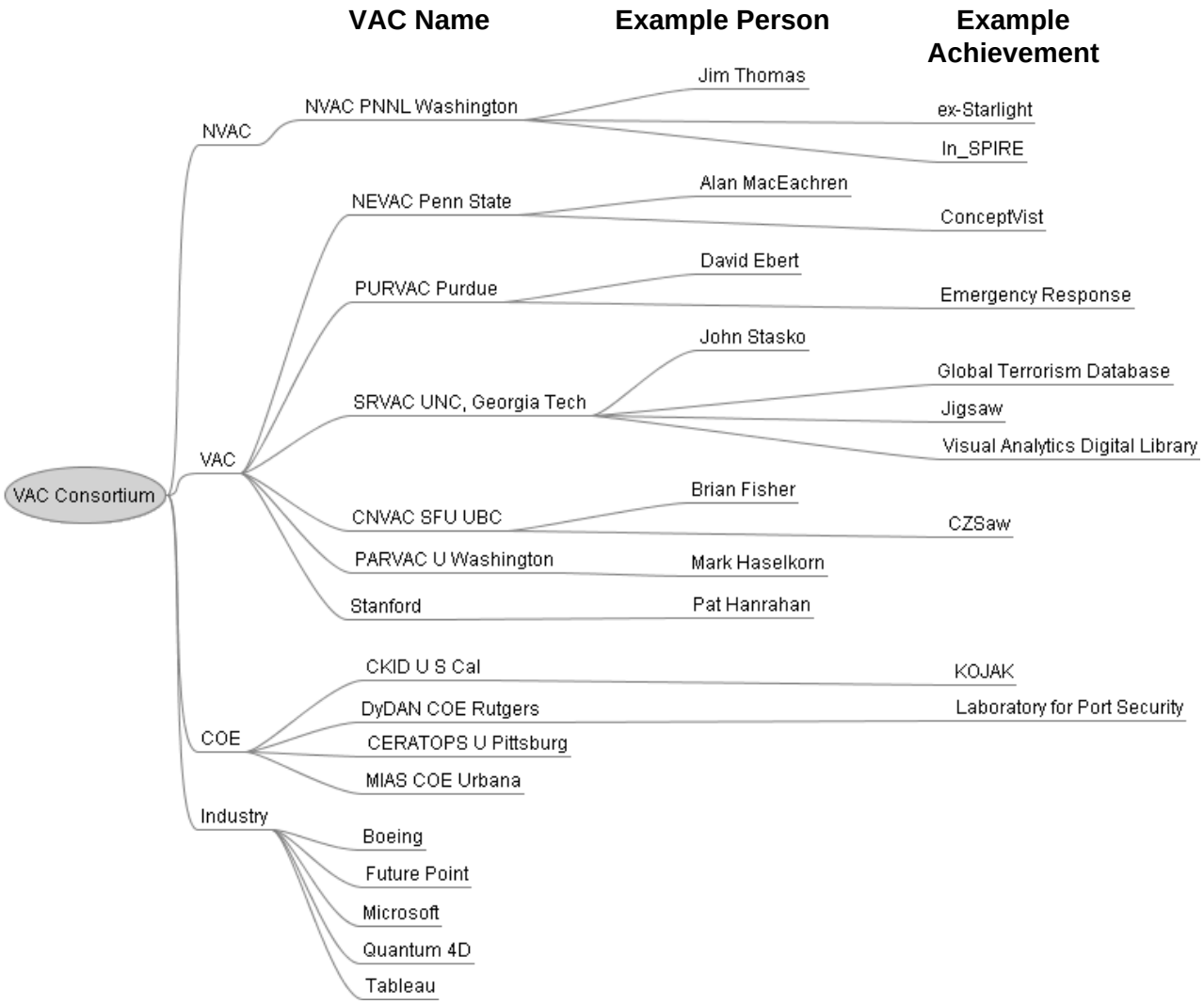


Figure 3-2 Research Centers in the Visual Analytics Consortium

The VAC consortium includes a network of Visual Analytics Centers (VACs) coordinated by the National Visual and Analytics Center (NVAC) in Richland Washington. (based on [41]) This diagram does not show the VA capability users such as DHS.

3.2.4 VACCINE and FODAVA

The DHS re-organized the funding mechanisms for Visual Analytics in 2008 and 2009, focusing on the visual analytics collaborations illustrated in Figure 3-3:

- Most of the RVACs are being transitioned into the Visual Analytics for Command Control Interoperability Environments (VACCINE) [41] which is funded by DHS.

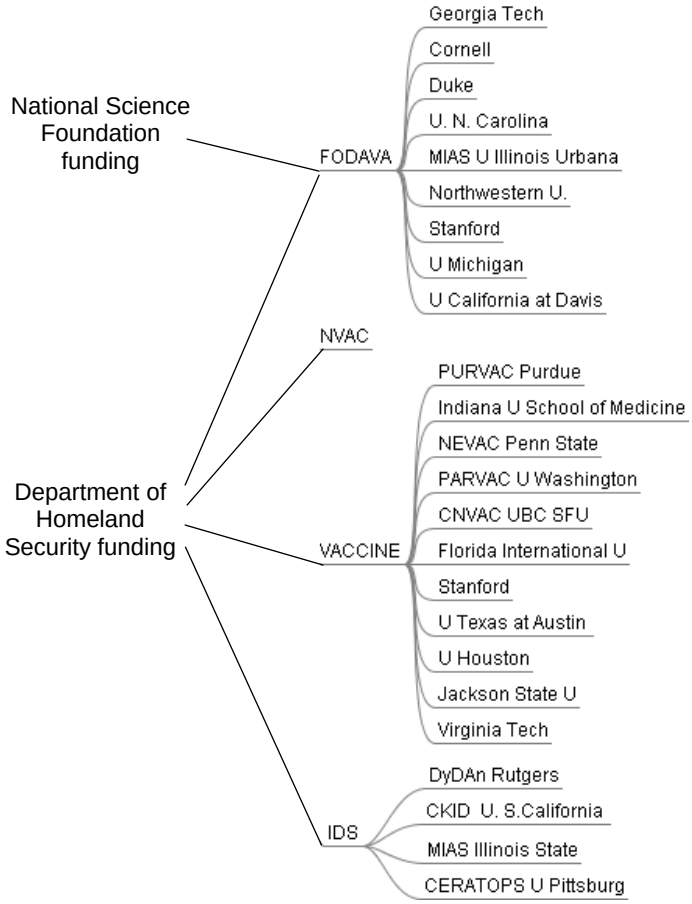


Figure 3-3 VACCINE, NVAC, IDS, and FODAVA in 2009

VACCINE is the DHS-funded umbrella organization for 12 partners focused on Command, Control, and Interoperability requirements of DHS. FODAVA has 9 partners focused on more foundational visual analytic science, funded by both DHS and NSF (based on [41]). The Institute for Discrete Sciences (IDS) is a group of four centers of excellence co-funded by DHS.

- The SRVAC and some university partners are now under Foundations on Data Analysis and Visual Analytics (FODAVA) [43] which is funded by both DHS and the US National Science Foundation (NSF).
- Some COEs are now part of the Institute for Discrete Sciences (IDS) which is funded by DHS.

VACCINE, led by Purdue, is focused on seven Command Control Interoperability (CCI) directives, and has two types of program:

- 4 long-term research streams (“pillars”).
- 15 shorter-term “Mission Guided Projects”.

FODAVA, led by Georgia Tech, is more focused on scientific foundations of the data and visual analytics fields and advancing the state-of-the-art.

The NVAC and the four agencies of the Institute for Discrete Sciences (IDS) continue to be funded by DHS.

3.2.5 Visual Analytics in Europe

A 2007 paper by Kohlhammer [79] indicates that at that time there were no significant Visual Analytics initiatives in Europe. In October 2008, a web page at the University of Konstanz, Germany [132] announced the initiation of "VisMaster," a European initiative in Visual Analytics involving 17 partner agencies in 9 European countries. This is repeated in an IEEE article in 2009 [80]. The "News" page of the Konstanz site, however, has not been updated since March 2009, and the links that it offers often make no reference to VisMaster or Visual Analytics. Clearly VisMaster is still ramping up.

The following VisMaster sites are worthy of note, though not all describe their research as "visual analytics":

- Fraunhofer Institute for Computer Graphics Research (IGD) in Germany [65]: A core research topic is Visual Analytics for interactive visualization and intelligent complexity reduction, which they understand to be an interdisciplinary combination of data mining and information visualization. Notable researcher: Jörn Kohlhammer.
- Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS) in Germany [59]: Focused on temporal and geospatial data, including people, cars, animals, eye movements, weather records, earthquakes, or traffic accidents. Notable researcher: Gennady Andrienko.
- Chair for Databases, Data Analysis and Visualization, University of Konstanz in Germany [133]: Focused on techniques for interactive mass data analysis for very large multidimensional and geographic data sets, clustering methods and index structures for high-dimensional spaces, and multimedia similarity search (2D and 3D). Researcher leader: Daniel A. Keim.
- AVIZ, Institut National de Recherche en Informatique et en Automatique (INRIA), in France [66]: A multidisciplinary team trying to improve the analysis and visualization of large and complex datasets by combining analysis methods with interactive visualizations. The focus is on the visual analysis of large networks (on the order of one million vertices and millions of edges) and time series (logs with billion of records captured continuously in real-time). Research leader: Jean-Daniel Fekete.

THIS PAGE INTENTIONALLY LEFT BLANK

4 LITERATURE REVIEW

The following subsections review the literature available on visual analytics that is relevant to maritime domain analysis. Section 4.1 begins with a review of key sources, such as journals, conference proceedings, and websites of research centers. Information sources associated with commercial companies are left to Section 5. Section 4.3 provides a topical review of the literature. Section 4.3.8 provides a brief introduction to the Annotated Bibliography which is in Appendix B.

4.1 Sources for Research Papers

The literature survey was conducted mostly via internet links indexed by Google and Google scholar. Visual Analytics journals (Section 4.1.1) and conferences (Section 4.1.2) provided rich lists of links, and each paper provided further links in the citations. The websites of key research institutes (Section 4.1.3) were also helpful.

4.1.1 Visual Analytics Journals

Academics generally publish Visual Analytics research papers in one of the following journals:

- IEEE Transactions on Visualization and Computer Graphics (TVCG) [64] or
- Information Visualization, [102].

The NVAC publishes *VAC Views* magazine [93] which provides good insights into activities around the VAC Consortium.

A new journal specifically dedicated to visual analytics has been announced, but the first issue will not be published until 2010:

- International Journal of Visual Analytics for Advanced Information Management (IJVAAIM) [50].

A careful review revealed no Visual Analytic stream in any of the Association for Computing Machinery (ACM) journals (TAP, TOCHI, TKDD), except for one special issue of SIGKDD Explorations [1].

4.1.2 Visual Analytics Conferences

The following conferences and workshops are focused on visual analytics:

- IEEE's *Visual Analytics Science and Technology* (VAST) [62].
- ACM's *Workshop on Visual Analytics and Knowledge Discovery* (VAKD) [7].

Other conferences that include some visual analytics papers, or seem to overlap in an important way are:

- IEEE's *International Conference on Coordinated & Multiple Views in Exploratory Visualization* (CMV) [60].
- International Cartographic Association's *Geospatial Visual Analytics Workshop* [67] September 2008.
- SPIE's *Defense, Security, & Sensing Conference* has a small *Visual Analytics for Homeland Defense and Security* conference track [121].
- GI Science's 2006 workshop on Visualization, Analytics & Spatial Decision Support [117].
- A one-day, 10-paper workshop within EuroVis 2009 [63], sponsored by VisMaster.

DHS Science and Technology branch sponsors the following conferences to discuss visual analytics research activities and related topics. They do not publish proceedings:

- VAC Consortium meetings, held at least twice a year. The NVAC Consortium webpage [96] provides links to meeting agendas and speaker biographies, but no viewgraphs or conference papers.
- DHS University Network Summit, held annually. A glossy brochure [34] is published that gives agendas and very brief synopses of each talk, but no viewgraphs or conference papers.

4.1.3 Teaching Library

The Visual Analytics Digital Library [48] provides a collection of about 240 lecture notes and homework assignments from the Georgia Tech center of excellence. They are organized according to the taxonomy shown in Figure 2-4.

4.1.4 Websites of Research Institutes

A large fraction of visual analytics research is done through VAC consortium labs, as listed in Figure 3-3 and in [37]. Some labs have web pages with links to publications, as summarized here:

- **National Visual and Analytics Center (NVAC)** [95] large-scale graph perception, analytic discourse and scenario understanding, mobile visualization platforms, statistical and semantic information representations and transformations, high dimensional information synthesis, visualization and interaction paradigms, temporal and spatial visual analytics, information packaging and dissemination, calibration and validation of information, collaboration technologies for distributed visual analytics, architectures for information-processing and visual analytics
- **Georgia Tech and U North Carolina (SRVAC)** [123]: evidence gathering, investigative analysis, hypothesis building, analytical reasoning, global terrorism data visualization, multimedia analysis, image and video visual analysis, semantic image browser, automatic news video analysis, Jigsaw visualization for investigative analysis, financial analysis, search spaces and search results, Visual Analytics Digital Library [48].
- **U. Illinois at Urbana (MIAS)** [91]: meaning-based information retrieval, automated text analysis using contextual patterns and probabilistic topic models, exploring the deep web (structured information sources), identifying hidden themes in massive datasets, learning the meaning of pictures, monitoring online communities.
- **Purdue University (PURVAC)** [104] data integration, analysis of anonymized data, disaster response, mobile analytics for emergency responders, personnel tracking and video capture for emergency response, sensor-driven video analytics, analysis of social networks, zoonotic disease spread, time-space analysis for disease surveillance, and network flow monitoring and forensics.
- **Penn State (NEVAC)** [94] knowledge-enabled, geographically aware visual analytics, FactXtractor and TexPlorer for information extraction and visualization in text documents, FEMARepViz and GeoViz Toolkit for automatic information extraction in geo-temporal-attribute visualization, Health GeoJunction tracks indicators of infectious disease threats, “Improvise” provides rapid VA prototyping, CiteSpace tracks trends in a volatile information environment, SemanticNetSA assesses evidentiary value ConceptVista provides a visual environment for ontology development NeoCITIES Geo-Tools provides a scaled-world simulation to mimic real-life civic emergencies.
- **University of Washington** (PARVAC)[134] distributed cognition and VA for Pacific Rim public safety and security, RimSimis a role-playing collaboration testbed for simulated emergency scenarios, a geo-spatial model of an urban environment, and geo-spatial pre-deployment of emergency supplies.

- **SFU / UBC (CNVAC)** [26] Spatial cognition in VA environments: seeing patterns in data, enactive cognition in VA environments: human-information dialog (sensemaking), distributed cognition in VA environments: collaborative and competitive analytics.
- **Stanford** [122] applications drawn from transactional analytics, scalable visual analysis over large temporal data sets, network security investigations, heterogeneous information spaces, perceptual efficiency in visual attention and cognitive load.
- **U. Pittsburg (CERATOPS)** [22] information extraction from unstructured text, detecting opinion and sentiment types, automating fine-grained interpretation of opinions, exploiting semantics.
- **Rutgers (DyDAn)** [36] analysis of large, dynamic virtual communities, optimal decision-making under uncertainty, Laboratory for Port Security developing data analytic tools, inspection strategies, and event mitigation for Port Security, sensor management for nuclear threat detection, cross validation of data in a privacy-preserving manner, information theoretic measures for biosurveillance, augmenting information in ontologies.
- **U. Southern California (CKID)** [57] extract semantic graphs from large data collections, fuse and integrate data at the semantic feature level, automated discovery of complex relationships in semantic graphs, unstructured text analysis, uncertainty quantification, through knowledge-based inference and information theory.

4.2 Domain of Interest

This section proposes a set of visual analytics topics that are of particular interest for maritime domain awareness. The analysis is based on:

- The visual analytics typology proposed by Jim Thomas and presented (with some changes) in Figure 2-2 and Figure 2-3.
- An analysis [30] of Canadian Forces requirements, including a list of 9 potential visual analytics applications.

Table 4-1 shows how the goals and data types can be associated with the potential applications. Note the following patterns in the table:

- Surveillance Coverage is the simplest column – it requires the fewest data types and has a narrow range of goals. This might indicate that it is a good candidate for early implementation, or it might suggest that this problem is too simple to be called Visual Analytics.
- There is little or no requirement for scientific analysis, audio signal analysis, transaction tracking, or analysis of digital libraries.

- Wide Area Surveillance, Intelligence Report Analysis, and Special Events have the most complex goals and require a wide range of data types.
- The VOI Dossier analysis could benefit from virtually any type of data available.
- Almost all potential applications are exploratory – the RJOCs need to explore their domain for the unexpected.
- All the potential applications involve visualizing time.

Although not shown in the table, visual analytic tools will need to support:

- Schneiderman's standard visual analytic sequence (Section 2.2): overview, zoom, filter, drill-down, view links, show history, extract information.
- Easy methods for clearly communicating information to the Admiral.

Predictions and "what-if" analyses are also important, as evidenced by Cdr Renaud's definition of Situation Awareness:

> Situation Awareness is the cognitive product of combining the operating environment with the subjects of interest, their activities, and any available intelligence, to infer and weigh potential outcomes over time. ([105] pg 5)

4.3 Topical Review of the Literature

The literature survey was split into the topics shown in Table 4-2 and discussed in Sections 4.3.1 through 4.3.11.

Table 4-1
Maritime Applications Cross-Referenced to Goals and Data Types

● Major Requirement
◖ Minor Requirement
⊙ Possible Future Data Type

		VOI Dossier and Track	What is Normal Behaviour	Sensor Datastream	Intellipdeia Connections	Wide Area Surveillance	Surveillance Coverage	Knowledge Indexing	Text in Intelligence Reports	Special Event
Ref. Figure 2-2↓	Ref Task 2 →	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9
Goals	Confirm					●	●	●	●	●
	Explore	●	●		●	●	●	●	●	●
	Predict					●	●			●
	Scientifically Investigate						◖			
	Surveil		◖	●	●	●			●	●
	Watch / Warn / Alert	●		●	●	●			●	●
	Map Relationship	●	●	◖	◖	◖		●	●	●
	Create Structure	●	●		◖			◖	●	●
	Identify Rare Event		●	●		●			●	●
	Plan / Influence		◖		◖	●	●	◖		●
	Assess Competing Hypotheses					◖	◖		●	◖
	Collaborate					●			●	●
Data Types	Unstructured Text	●			●				●	●
	Structured Text	●	●	●	●	◖			●	●
	Complex Document	●			●				●	●
	Image	●			●			⊙	●	●
	Video	⊙	⊙			◖			●	●
	Voice Audio	⊙	⊙			⊙				⊙
	Sound Audio					⊙				⊙
	Cyber Transaction	⊙	⊙		⊙					●
	Finance Transaction	●	⊙							●
	Shipping Transaction	●	⊙			⊙		⊙		●
	Numeric Values	●	●	●	◖	●			◖	◖
	Graph Structures	●		●	●	●		●	●	●
	Databases / Files	●		◖	●	●	◖	●	◖	●
	Digital Libraries								◖	◖
	Model / Simulations		◖			●	●			●
	Geospatial Coordinates	◖	●	⊙		●	●	◖	●	●
	Time	●	●	●	◖	●	●	●	◖	●
	Name / Entity	●		●	●	◖		●	◖	●
	Uncertainty / Imprecision	◖	●	◖		●	◖	◖	●	◖

Table 4-2
Maritime Applications Cross-Referenced to Visual Analytic Topics

● Major Requirement
◖ Minor Requirement

Sec	Ref Task 2 ➔	5.1 VOI Dossier and Track	5.2 What is Normal Behaviour	5.3 Sensor Datastream	5.4 Intellipdeia Connections	5.5 Wide Area Surveillance	5.6 Surveillance Coverage	5.7 Knowledge Indexing	5.8 Text in Intelligence Reports	5.9 Special Event
4.3.1	Geo-Spatial-Temporal Awareness					●				●
4.3.2	Geo-Spatial-Temporal Data Mining	●	●							
4.3.3	Geo-Spatial-Temporal Uncertainty	●	●			●				●
4.3.4	Geo-Temporal Coverage Analysis						●			
4.3.5	Predictions and What-If Analysis					●	●			●
4.3.6	Classical Sensor and Network Analysis			●	●			●	●	●
4.3.7	Social Network Analysis				●				●	●
4.3.8	Collaboration					●		●		●
4.3.9	Textual and News Feed Exploration		●					●	●	
4.3.10	User Interfaces and Usability					●	●	●		●
4.3.11	Visual Analytic Design Principles									

4.3.1 Geo-Spatial-Temporal Situation Awareness

This section surveys visual analytic strategies that help analysts be aware of everything that is going on in a spatial region of interest, as a function of time, including "to infer and weigh potential outcomes over time" [105]. Note that not all the papers have an analytical component – some are just "Visualization."

Ship Track Analysis

- Andrienko discusses plotting ship tracks and multiple tracks ([3], [4],[6]).
- Chan discusses how to make the display responsive even when accessing very large numbers of tracks [23].
- Willems ([141-142]) describes a very specific 3D-like graphical strategy for visualizing track patterns in a very busy part of the North Sea, using AIS data. Tracks are interpolated and convolved with a kernel in such a way that the accumulated view represent ship density, rather than number of tracks (see Figure 4-1). Not visual analytics, but visually effective.

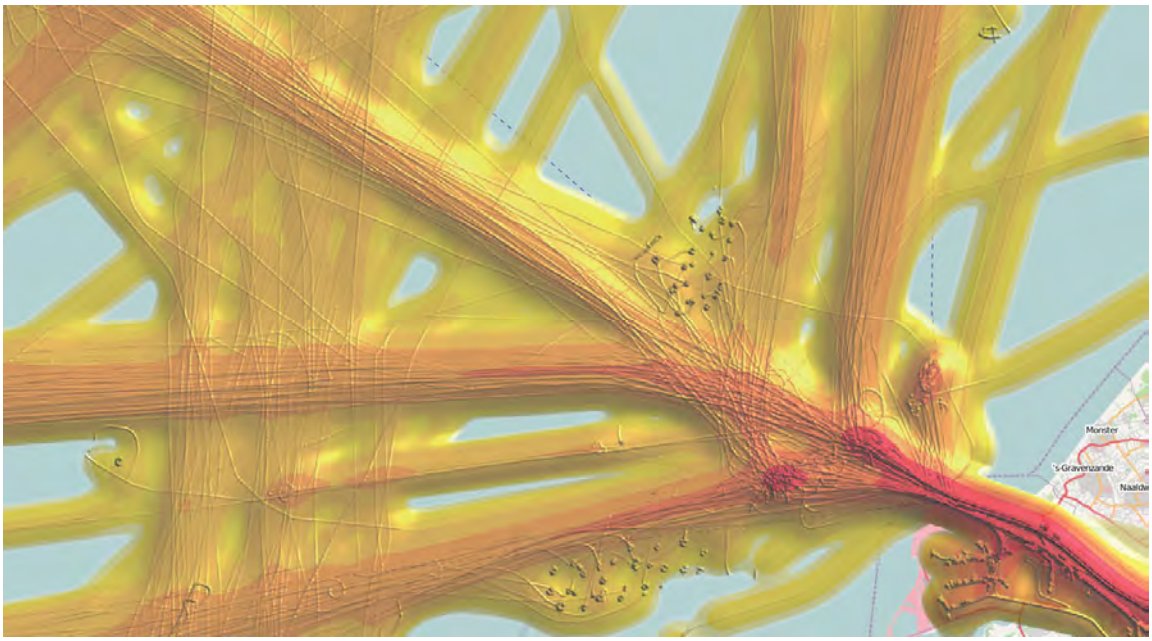


Figure 4-1 Willem's Ship Track Rendering
Willems has developed a striking visualization scheme, shown here representing ships approaching Amsterdam. (from [142]). The smooth, broad strands represent average ship density, and the superimposed fine ridges represent individual ship tracks. Raised dots are thus ships at anchor. A coloured wash is superimposed indicating ship density (ships per square kilometre).

Visualizing Motion

- Aigner [2] has a very helpful presentation reviewing many different ways to display time, and periodic events in particular.
- Few [40] uses a time-slider and leaves trailing marks behind to visualize change and motion.
- Mehta [87] has built a simple set of inter-linked windows for interactively visualizing time-periodic motion. Not as useful as other temporal tools.
- Yang [145] describes ideas for showing moving things superimposed on static display items.

Dynamic Non-Localizable Events

- Maciejewski [83] discussed visual analytics of geo-spatially distributed features that change with time, which may be relevant to the time-varying situational picture.
- Wright [143] proposes "blobology" to represent a distributed group or meteorological event, including the time-evolution of the shape and location of that group.

Coordinated Multiple Views

- Roberts [110] gives an overview of Coordinated and Multiple Views research, which is a core component of many Visual Analytics products.

Visualizing Spatio-Temporal Event Patterns

- Word clouds used to illustrate Tweet traffic during the superbowl [13] illustrate how effective and intuitive a simple time-slider can be. This should be viewed as a video, or better yet go to the website and interact with it.
- Mehta [87] shows very simple interactive visualization of periodic motion. Not visual analytics.
- Meiguins [89] demonstrates a spatio-temporal model of one of the VAST challenges, with link visualizations.
- Ho [54] demonstrates GeoAnalytics using coordinated multiple-linked views applied to a large ocean space volume dataset.

Kinematic Anomaly Detection

- Riveiro [109] describes a system that supports the acquisition of situation awareness with user involvement in the anomaly detection process using two layers of interactive visualizations. An interactive data mining module supports the insertion of the user's knowledge and experience.
- Riveiro *et al* [107] provide a useful discussion of the cognitive process of anomaly detection based on observations in Ops Centers.
- Hao [53] presents a way to visualize anomalies in massive streams of data.

Visualizing Threats

- The International Maritime Bureau publishes a Live Piracy Map [68] that illustrates the value of a very simple situational picture.
- The UN Institute for Training and Research (UNITAR) Operational Satellite Applications Programme (UNOSAT) [135] uses a number of clear visualization strategies for visual data mining of maritime events, as shown in Figure 4-2.

4.3.2 Geo-Spatial-Temporal Data Mining

This section looks for strategies to extract patterns from past behavior in a dynamic geo-spatial area of interest.

- Keim [76] outlines the advantages of visualization for data mining applications, and gives a long list of examples.

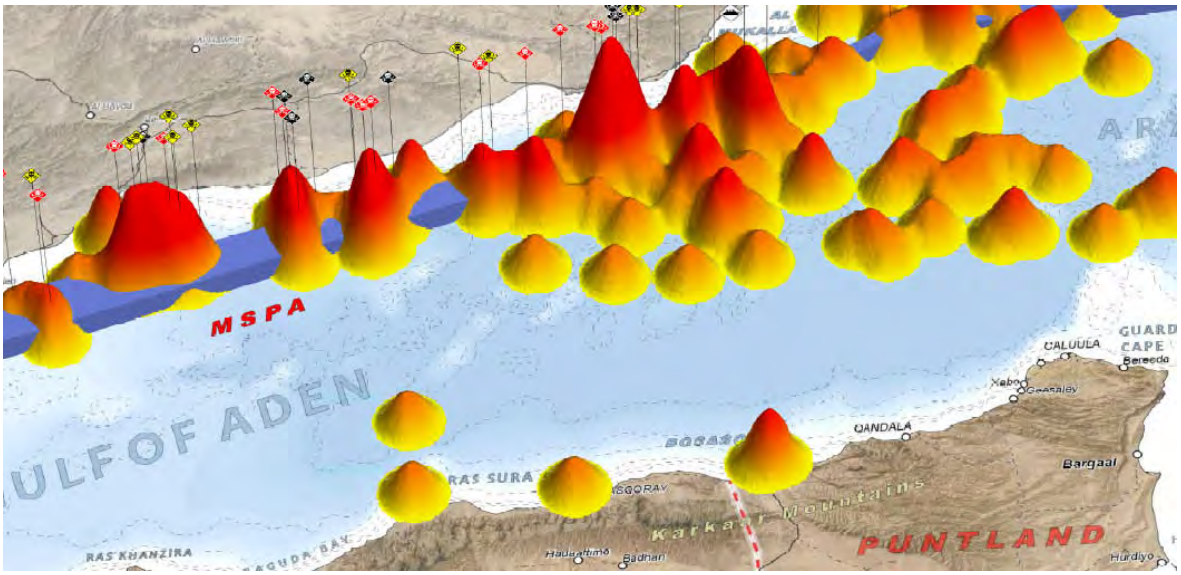


Figure 4-2 UNOSAT's Rendering of Pirate Activity Off Somalia
This excerpt from a custom-rendered report ([135]) illustrates the power of visual renderings for threat assessment. Red-tipped cones represent the density of pirate attacks in the Gulf of Aden in 2008. The Maritime Security Patrol Area (MSPA) is shown as a darker blue band, and each attack that occurred within that band are noted with small "marker pins." This plot, together with other analyses, showed that the pirates had focused their attention on the MSPA after it was established in mid-2008.

Ship Normal Routes in Time

- Andrienko [4] displays methods for visualizing average speed at each spatial location, and then (more interestingly) unwitting groups of vehicles (or vessels) that follow the same route independently, as in Figure 4-3.
- Chan [23] describes an architecture for keeping a visual analytics system responsive even when indexing massive time series datasets.
- To simplify the RMP it may be helpful to find common patterns in the shapes of ship tracks, using an automated tool to indicate whether two tracks have a similar shape. Schreck [116] looks at using a self-organizing map for that purpose. This research uses Visual Analytics to help guide the self-organizing map to create the tool.

Time and Location Patterns of Past Events

- Fails shows a simple multi-view tool that highlights when extended events overlap in time [38].
- Jern [70] uses multiple coordinated views to explore spatio-temporal patterns.
- Bak [9] has an original mechanism for summarizing the timing of observed events.
- See also the UNOSAT [135] report mentioned above.

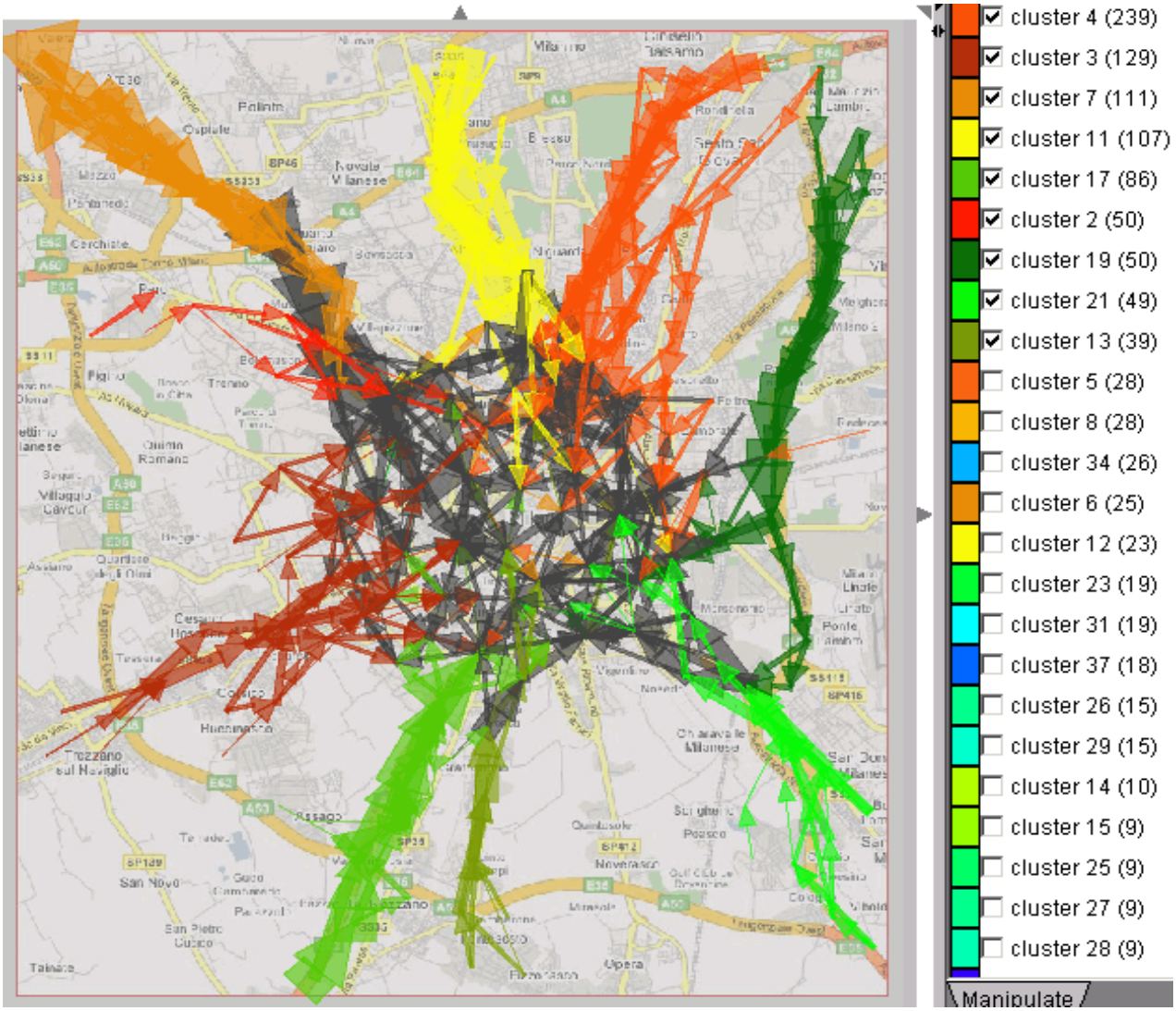


Figure 4-3 Andrienko's Clusters of Trajectories

Some "clusters" of cars driving onto Milan unwittingly follow the same route as many other cars. Visual Analytics is here being used to identify those clusters. In a maritime domain, they might be clusters of ships all heading for a particular port of seaway (from [4]).

Data Mining Ship Attribute Data

- Hao [52] shows how to transform a very large multi-attribute time series into a series of coloured icons, with the shape of the icons encoding the multiple attributes so that changes over time can be seen visually.
- Wilkinson *et al* [140] suggests that we need visual analytics for three principal purposes: checking raw data for anomalies, exploring data to discover plausible models, and checking model assumptions. This paper looks at finding patterns in very high-dimensional data, using statistical transformations to re-project the data

and thus reveal the patterns, and plots that link large numbers of two-dimensional views (usually scatter plots) of the data.

Making Visual Analytic Systems Better

- Sifer [119] defines metrics to compare interfaces for interactive exploration of hierarchical multi-dimensional data, and uses those metrics to evaluate various visualization strategies.
- Chen [25] lays out a knowledge management methodology that should (he suggests) work in parallel to the visualization, as part of the visual analytics.

4.3.3 Geo-Spatial-Temporal Uncertainty

- Jones [72] makes a serious attempt at representing uncertainty in a maritime situation map, in this case using "squarified treemaps." Not entirely successful.
- Riveiro [106] looks at uncertainty representations in a number of fields, from graphical rendering to surveillance displays, but does not come up with definitive recommendations about how it should be done.
- Xie [144] describes various ways to visually reveal errors or data quality problems in individual numbers, whole records, or data sources.
- Falkman [39] indicates that VISAD is engineered to represent uncertainty, but gives no details about how, or what it looks like.

4.3.4 Geo-Temporal Coverage Analysis

There is no apparent work being done to develop visual analytics for sensor coverage analysis.

- Matthews [85] proposed a shaded-area approach to surveillance coverage maps, and has some CF analysts test them. His focus was on visualizing the spatial extent of coverage, but not its senescence.
- Mewett [90] delivers one of very few papers that looks at visualization of sensor coverage patterns over time. He implemented a solution in which coverage areas fade with time, to indicate that the data is stale. Not visual analytics yet, but could be the foundations for it.

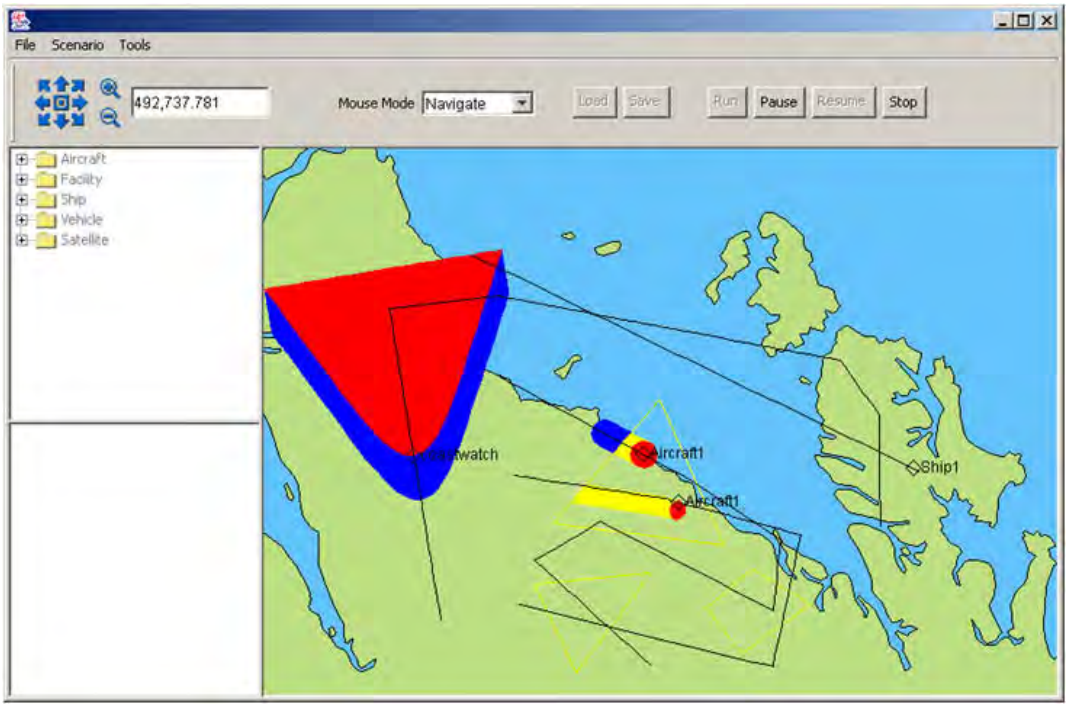


Figure 4-4 Mewett's Display of Sensor Coverage

Black lines are flight lines of surveillance aircraft, and yellow patches show recent sensor coverage from the aircraft, projected onto the ground. (from [90]) This is neither the fanciest visualization nor the most complicated algorithm, but it is so rare to find any researchers caring about sensor swaths, that it deserves extra visibility. More work needs to be done in this area.

4.3.5 Predictions and What-If Analysis

Predictions within the Current Plot

- Yue *et al* [146] describe an AI blackboard-based agent that leverages interactive visualization and mixed-initiative problem solving to enable analysts to perform predictive analysis on large amounts of data.
- Sofrelog [120] provides support for predicting future motion of a ship.
- The Thetus Intelligence Fusion Platform [127] claims an ability to "Create cause-and-effect scenarios to determine best course of action, plan for contingencies, and maximize resource allocation," which may indicate this capability.

Virtual World

Visual analytics may one day take the form of very detailed multi-player simulations to extract predictions of the long-term outcomes of various tactical choices. Defence scientists are thus interested in Virtual World research.

- May [86] leads a panel discussion to introduce the domain of visual analytics to a virtual reality (VR) and artificial reality (AR) audience and explore how and where VR/AR research can be adapted for use in visual analytics.
- Magazine articles [16] [112] and [17] provide non-technical overviews of how the military is experimenting with virtual worlds.

4.3.6 Sensor and Network Analysis

There are very many papers on *visualizing* digital networks, but not so many on *visual analytics* for network surveillance or network analysis. No papers were found that specifically focused on sensor functionality.

Watching for Network Failure or Intrusion

- Burner [19] describes *First Look.*
- Mansmann [84] describes a visual analytics solution for network monitoring.
- Meier [88] focuses on ways to visualize network behaviour as a function of time, using innovative visual patterns as shown in Figure 4-5.

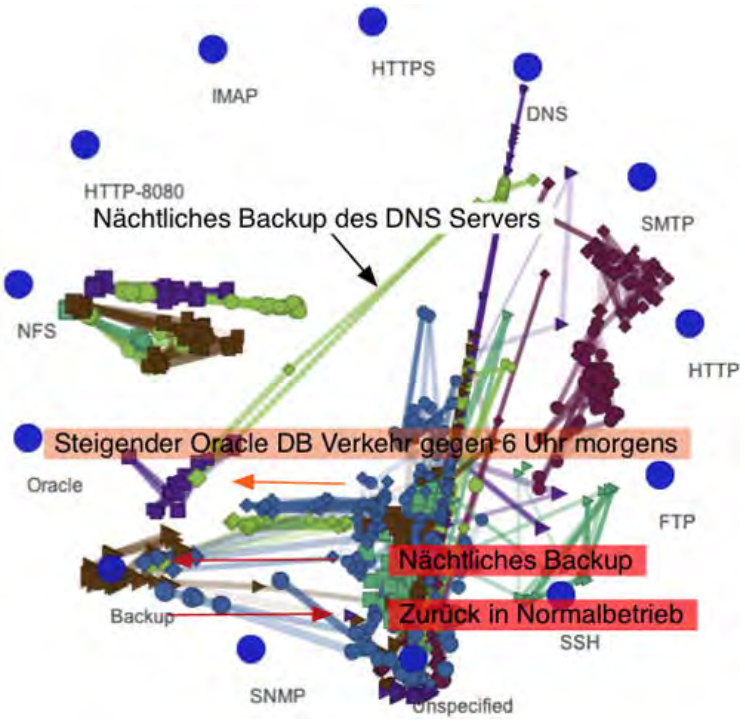


Figure 4-5 Meier's Visualization of Network Time Series

Meier focuses on how network information (e.g., load profiles, port information, IP packet information, etc.) change with time. This might be applicable to monitoring of sensor networks.

Exploring Node-Linked Spaces

- Carlsen [20], [21] describes an interactive visualization (almost visual analytics, but lacking the ability to build a model) that was created for an art project.

4.3.7 Social Network Analysis

Public Social Networking (Twitter, Facebook, Wiki, etc.)

- Barash [10] has an Excel plug-in for analysing social networking traffic. This could become important if the CF adopts social networking as a medium.
- A delightful dynamic visualization [13] of social networking during the superbowl illustrates the power of a simple concept well implemented.
- Suh [126] shows how visualization and visual analytics can provide important insights into Wiki-type collaborative knowledge bases (such as Intellipedia for example).

Social or Vocational Relationships

- Godwin *et al* [51] demonstrates how gene-sequencing algorithms can be used interactively to identify patterns of collaboration among criminals.

Time Evolution of Networks

- Kapler [73] proposes “Configurable Spaces” as a way to view the time-evolution of arbitrary and abstract network maps.

4.3.8 Collaboration

- Brennan [15] clearly describes a collaboration architecture that appears to be suitable for jointly developing the Maritime Picture.
- Hollan [55] suggests a new “distributed cognition” paradigm is needed to thinking about human-computer interaction in a distributed visual analytic system.
- Bowman *et al* [14] lay out management methodologies and team interaction standards to be used when scientific teams from different agencies and different allied countries have to work together intensely.
- Keel [75] describes a comprehensive and information-rich report on a collaboration architecture "EWall" where people engaged in the visual organization of information using graphical objects (Cards) share their work via software agents.

- Vernik and Bouchard [136] describe Imago, a distributed environment that supports visualization, and thus a candidate for hosting collaborative visual analytics.
- Weaver [139] suggests collaboration can be achieved by giving separate users coordinated and linked views of the analysis space, and giving managers tools to "metavisualize" the data.
- Robinson [111] ran experiments to watch how people collaborate, and then built an architecture to support the various approaches that they used.
- The Starlight video [101] suggests that it supports collaboration, but by “collaboration” it seems to mean either a) two people sitting at the same terminal or b) using starlight graphics to brief a larger group.

4.3.9 Textual and News Feed Exploration

- David Fisher [42] has built a text-analysis tool that looks for themes and associated keywords, and then tracks how those keywords evolve over time.
- Luo *et al* [82] have built a prototype news analysis system that identifies news clips by topic and provides a visual exploration medium.
- Ghoniem *et al* [49] use a Theme-River-like graphical portrayal to show how topics in the news (gleaned from the close captions of all-news television stations) vary with time.

4.3.10 User Interfaces and Usability for Visual Analytics

- Butkiewicz *et al* [18] found the multi-touch table to be very popular and intuitive.

4.3.11 Visual Analytic Design Principles

- Andrienko et al [5] lay out a manifesto for “GeoVisual Analytics” as a sub-type of visual analytics.
- Pere and Schneiderman [103] discuss the tight link between visual analytics and data mining.
- Betini [12] suggests that data mining and data visualization need to be better coordinated.
- Chaomei Chen [24] uses information theory to guide visual analytic systems so that the visualizations are not deceptive.

4.4 Guide to the Bibliography

The annotated bibliography is attached as Appendix B. It lists all the papers and web sites that were collected, examined, and referenced in the text.

4.4.1 The EndNote Database

A total of 213 references were inserted into the EndNote database, as shown in Figure 4-6. References were collected systematically as follows:

- Searches were done on the phrase "visual analytics" in IEEExplore, SPIE Digital Library, and ACM Portal, and the abstracts for every paper found in those three databases were examined. Papers on topic for this study were then downloaded and scanned to confirm relevance before being included.
- Searches were done using Google and corporate links, for the web pages of every regional VAC member, Center of Excellent, or FODAVA partner. On those web pages, references to relevant technology were followed up if possible.
- Searches were done on Google for "visual analytics" and "maritime" with "analytics" plus other searches on specific topics such as "visual" and "collaboration."

Almost all the relevant references were from the past 4 years, as shown in Figure 4-7.

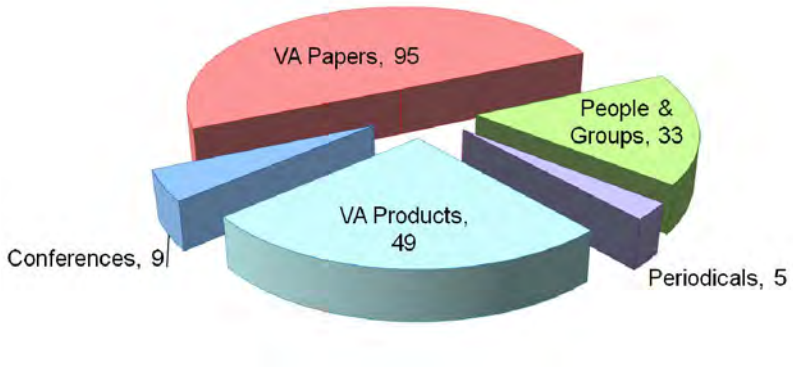


Figure 4-6 Scope of the Literature and Product Search

The literature search focused mainly on visual analytics papers (95 were collected in the Endnote database) and on visual analytic products (49 were collected). The database also includes a total of 47 references to visual analytics people, groups, conferences, and periodicals.

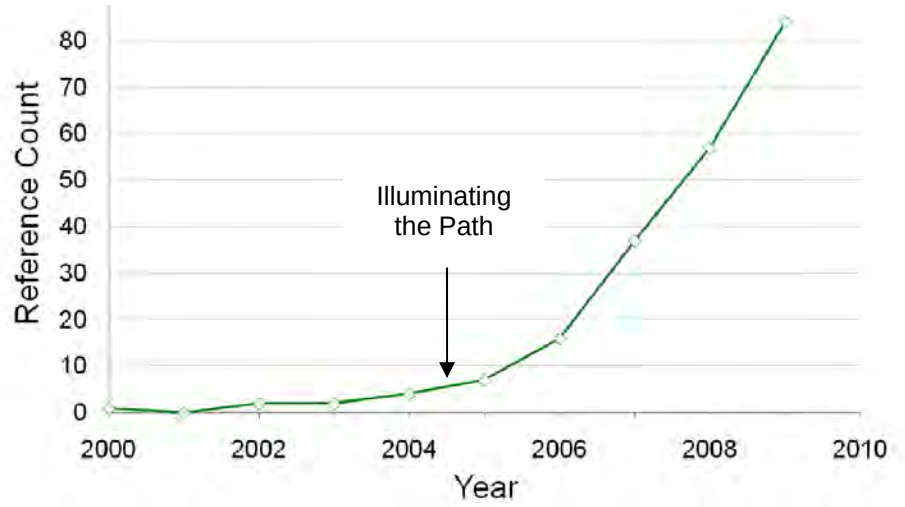


Figure 4-7 Age of the References

Almost all of the visual analytics references in the EndNote database were published since the term "visual analytics" was established by Thomas's 2005 book "Illuminating the Path" [131]. There are 213 references to papers, institutions, and relevant websites, 144 of which are listed in the annotated bibliography.

4.4.2 Annotated Bibliography

The Annotated Bibliography in Appendix B lists those items in the database that are particularly relevant to the Maritime Domain.

As shown in Figure 4-8, the bibliography provides standard citation information, plus our assessment of what is valuable in the article, product description, conference, or group website. If a copy of the article was delivered with this report, the filename is also listed.

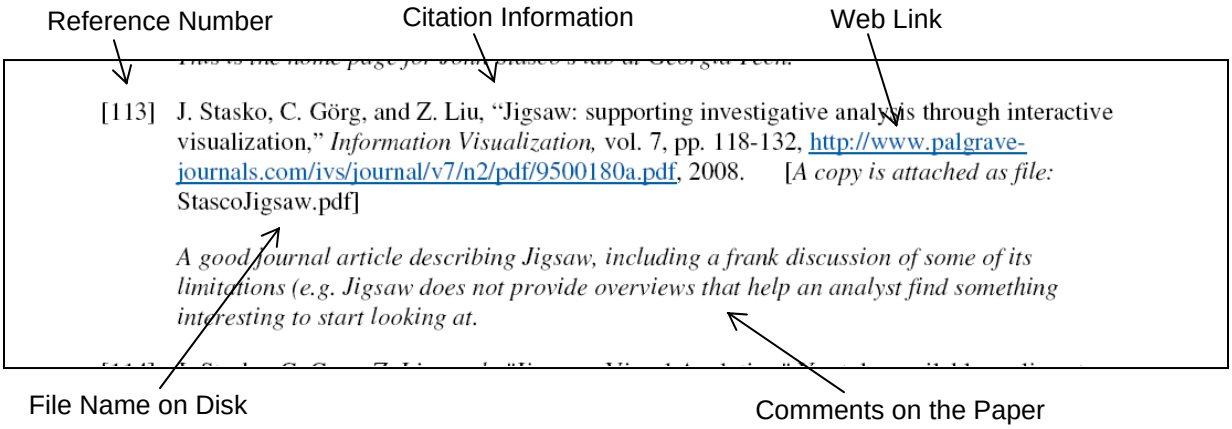


Figure 4-8 Example Bibliography Entry

The bibliography provides standard citation information such as Author(s), Title, Journal or Conference name, Location, and Date. If possible, it also provides a web link from which the paper can be acquired. If a copy of the paper is included on the distribution disk, the name of that file is also provided. Our assessment of the paper is summarized in a separate paragraph immediately following the citation, in italics.

5 PRODUCT REVIEW

Table 5-1 through Table 5-15 summarize a number of visualization and visual analytic "products" that were assessed. In accordance with the contract scope, the products were not installed and tested. Each table provides a visual summary of the product, often in the form of a screen grab, plus a written description of what the product does. The question of whether the product is truly "visual analytics" is addressed by tabulating its conformance to the first five rules in (2-2) through (2-6). References are provided for each product, and if a video was available for download, the filename of an .avi file is provided.

Geographic Analytics

The strengths and weaknesses of the seven software systems that are particularly strong at visualizing geo-spatial information can be summarized as follows:

- **Starlight:** (Table 5-1) Excellent Visual Analytics credentials and capabilities. It does provide geo-spatial support but most of its energy is focused on text and link analysis. No indication of true support for collaboration. User interface is perhaps too complex for RJOC analysts to use routinely.
- **GeoTime:** (Table 5-2) Very good Visual Analytics credentials, but focused on geo-spatial-temporal renderings and hence a narrower visualization range. RJOC leaders liked its appearance, but thought it might be too complex for routine analysis. Not collaborative.
- **Palanterra:** (Table 5-3) Apparently not very visually sophisticated and hence not really Visual Analytics. But has good collaboration.
- **ENVI *N*-Dimensional Visualizer:** (Table 5-4) a true visual analytics tool, deployed long before Visual Analytics was a recognized term, but focused very specifically on ground classification and target detection and hence a very narrow visualization range. Not collaborative.

- **VISAD:** (Table 5-5) a true Visual Analytics tool that already supports maritime surveillance. There is some concern that the visualizations are too conceptual and thus it might not be popular in the RJOCs.
- **GeoAnalytics Visualization (GAV):** (Table 5-6) an excellent collection of sophisticated visualizations, with good support for exploration and discovery, but no apparent support for analytics (i.e. building a case).
- **Command Post of the Future:** (Table 5-7) highly interactive, analytical, and collaborative, with good visualizations. But the visualizations appear to be much less sophisticated than classic Visual Analytics.
- **Sofrelog:** (Table 5-8) state-of-the-art commercial application for displaying the maritime picture, includes some support for collaboration and predicting future tracks. Lacks enough visual sophistication to be true Visual Analytics.

Textual Analytics

The following five systems are all focused mainly on analyzing database records and textual data,

- **In-Spire:** (Table 5-9) with a truly impressive list of visualizations and Visual Analytics features, the only concern here is that the user interface may be difficult and slow to learn. The Assessment Wall ([99]) is an attempt to reduce that complexity.
- **Jigsaw:** (Table 5-10) a very powerful Visual Analytics tool that is popular with analysts because it is very simple and intuitive to use.
- **Analyst's Notebook:** (Table 5-11) seems to be moving from being primarily a visualization and report-generating tool toward true "analytic" capability where a storyline is crafted by the analyst. This has been installed in the RJOCs for many years but is not used regularly because it takes too long to get the data into the system (and much of the interesting non-tracking data is behind firewalls).
- **Visualinks:** (Table 5-12) appears to be trying to compete with Analyst's Notebook but with even less "analytic" capability. They mention collaboration but it sounds like a product-sharing capability rather than an "analysis process" sharing capability.
- **Thetus Intelligence Fusion:** (Table 5-13) uses similar data and works toward similar goals as Analyst's Notebook and Visualinks. The major difference is that they have a clear analysis track, using an embedded ontology and visualization, by which the analyst can build understanding.

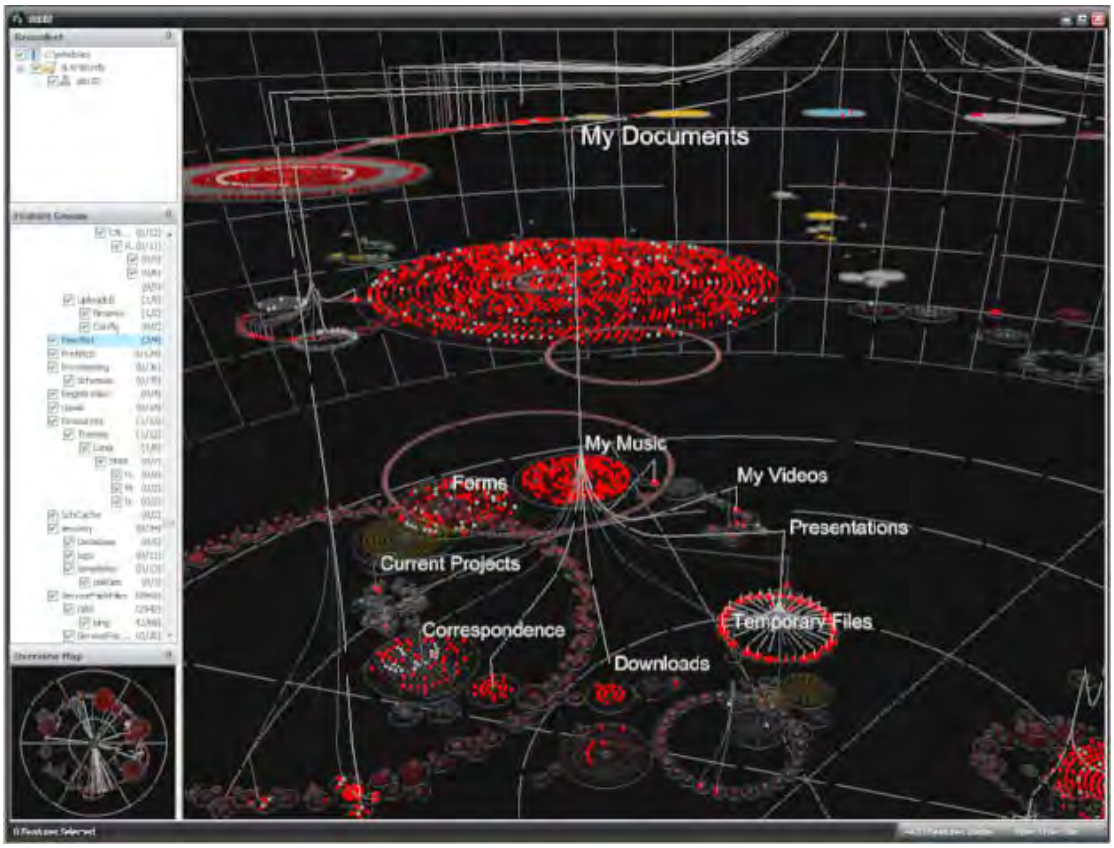
Knowledge Mapping

- **K-Mapper:** (Table 5-14) a sophisticated tool for exploring and discovering people, expertise, assets, and concepts. But it does not yet support interactive analysis – the building of the analytical "story."

Interface Hardware

- **3D Touch Table:** (Table 5-15) very impressive ability to “display” terrain in 3D. Probably not enough added value for the RJOCs to acquire one.
- **Assessment Wall:** (Table 5-16) is a large-format touch-sensitive display engineered to work with In-Spire software.

Table 5-1 Starlight



Starlight is perhaps the definitive Visual Analytics system. It provides advanced information visualization technology for graphically manipulating, understanding, and acting on very large quantities of complex and disparate information. Features: Advanced search and data filtering capabilities; Simplified data acquisition; Visual information analysis environment; Network diagrams; Free-text topic clustering; Geospatial relationships; Temporal relationships; Hierarchical organizations or collections of information; Categorical relationships; Multidimensional correlation of structured data; Advanced workflow management capabilities; Information fusion among disparate data sets; Multimedia data support. Currently Starlight is not set up for real-time operation.

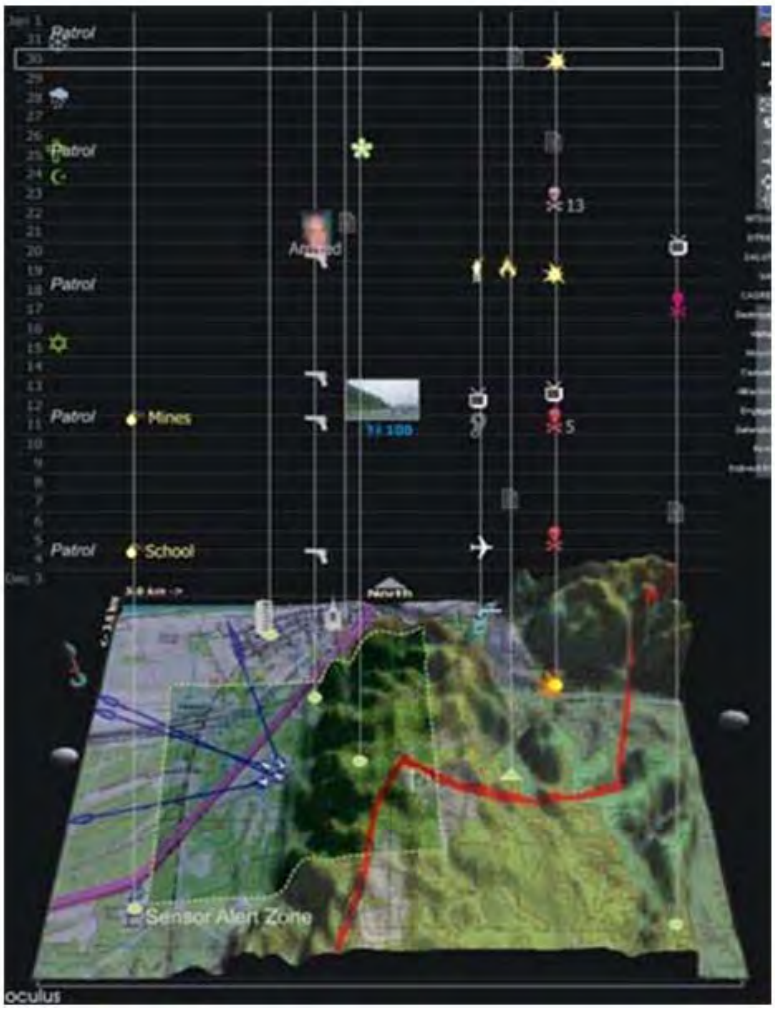
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collab: **N?**

Potential Maritime Application: VOI Dossier and Track, Intellipedia Connections, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: Future Point Systems Inc.	**Video:** Starlight_video.avi

References: [44] and [45] and [101] and[114]

Table 5-2 GeoTime



GeoTime was developed to improve perception of movements, events and relationships as they change over time within a spatial context. A combined temporal-spatial space was constructed in which to show interconnecting streams of events over a range of time in a single picture. Events are represented within an *X,Y,T* coordinate space, in which the *X,Y* plane shows geographic space and the *Z*-axis represents time into the future and past. In addition to providing the spatial context, the ground plane marks the instant of focus between before and after; Events along the timeline "occur" when they meet the surface. Events are arrayed in time along time tracks, which are located wherever events occur within the spatial plane.

Visual Soph: **Y/N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collab: **N?**

Potential Maritime Application: VOI Dossier and Track, What is Normal Behaviour, Wide Area Surveillance, Surveillance Coverage, Special Event

Vendor: Future Point Systems Inc.	**Video:** Geotime1.avi

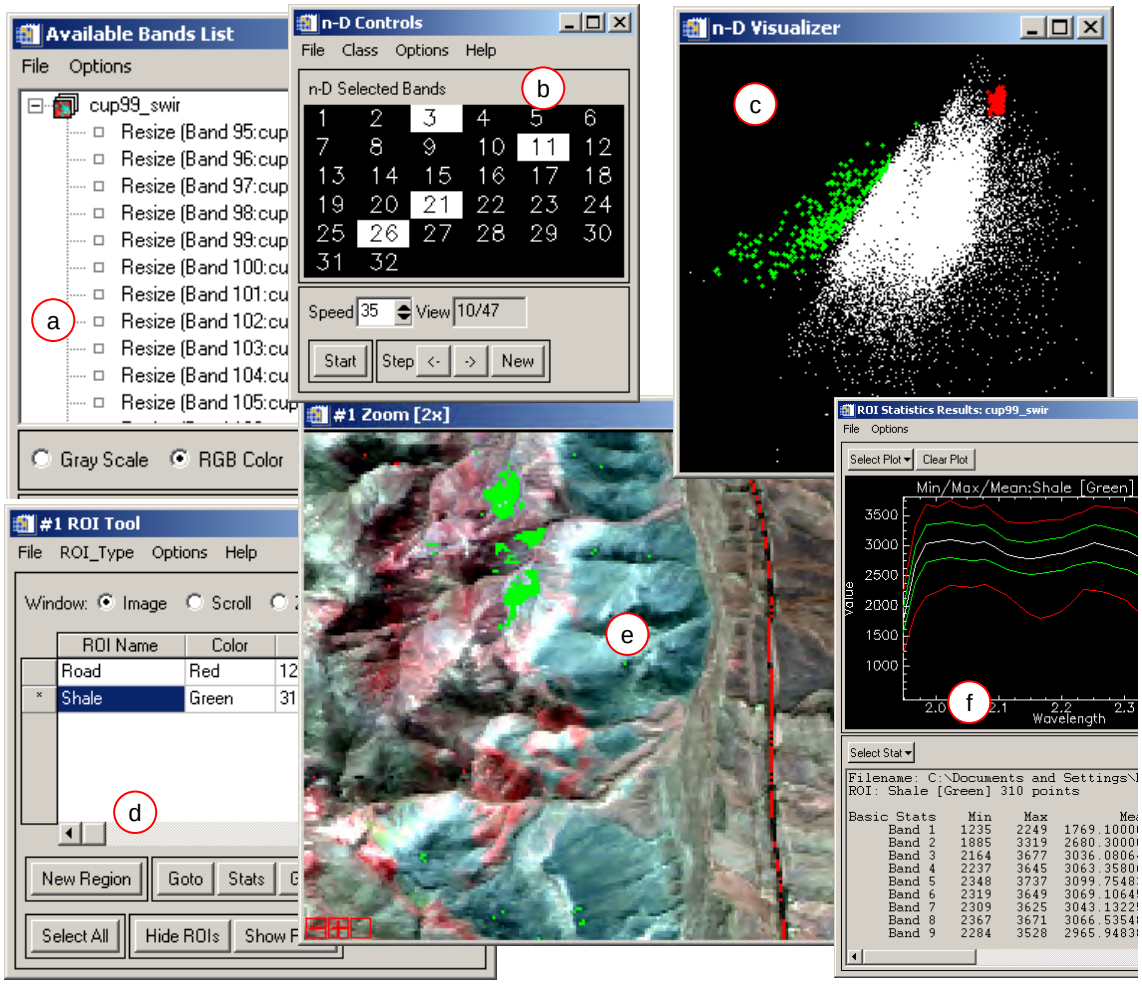
References: [74] and [97]

Table 5-3 Palanterra

Built using commercial-off-the-shelf software, Palanterra supports thick- and thin-client operations. Accessing Palanterra's national-level site provides critical infrastructure and asset data for the entire United States. Zooming to an urban site gives controlled access to high-resolution datasets of major cities. HSIP data are vector- and raster-based and include satellite and airborne imagery and light detection and ranging (LIDAR) data. Such products are employed to create virtual analytic environments for 3D analysis in support of national security events. One example is the use of such 3D models for line-of-sight analysis to ensure security at the 2002 Super Bowl in San Diego, California.

Visual Soph: **N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **N**	Collab: **Y?**
Potential Maritime Application: Special Event				
Vendor: US NGA			**Video:** none	
References: [11]				

Table 5-4 ENVI *N*-Dimensional Visualizer



The *N*-Dimensional visualizer (NDV) was engineered about ten years ago for extracting information from hyperspectral images. The operator opens an *M*-band hyperspectral image (a) and uses the NDV controls (b) to select a subset of bands (e.g. $N = 4$). The *N*-D Visualizer (c) slowly rotates an *N*-dimensional scatter plot in the window. If the operator sees a cluster, she can stop the rotation, circle some scatter plot points, and paint them a selected colour (red and green in this example). This creates corresponding regions of interest (d) which can be named by the analyst, and it marks with the correct colour all pixels in the geospatial scene with matching spectra (e). Note how the red cluster has identified the road. Statistics can be calculated for each ROI showing the mean spectrum (f) and standard deviation. Conversely, on operator can select a region in the geospatial scene and ask for all pixels in the NDV to be painted that colour, thus identifying similar pixels. The operator thus moves between four coordinated views: spatial, scatter plot, spectral, and regional.

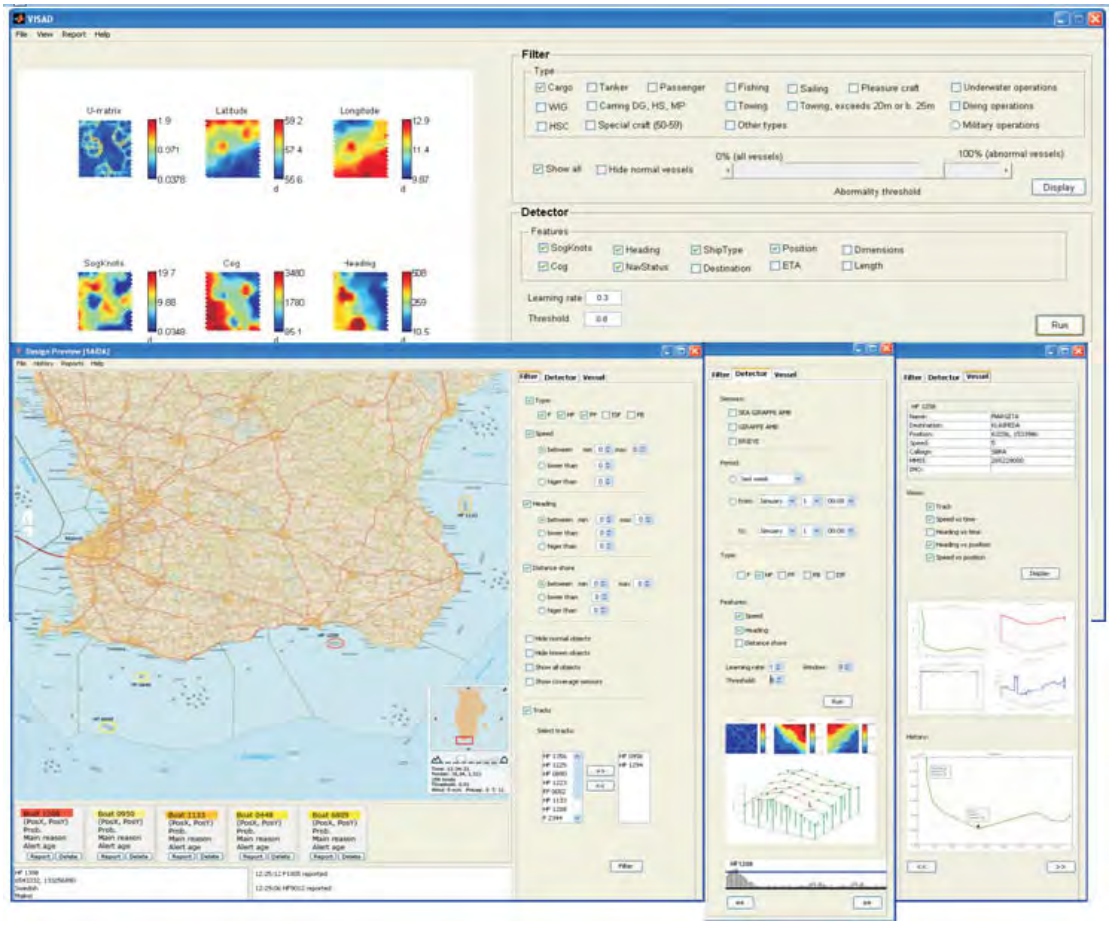
Visual Soph: **Y/N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collab: **N**

Potential Maritime Application: What is Normal Behaviour, Sensor Datastream, Intellipedia Connections, Surveillance Coverage.

Vendor: ITT	**Video:** EnviForestry.avi

References: [69]

Table 5-5 VISAD



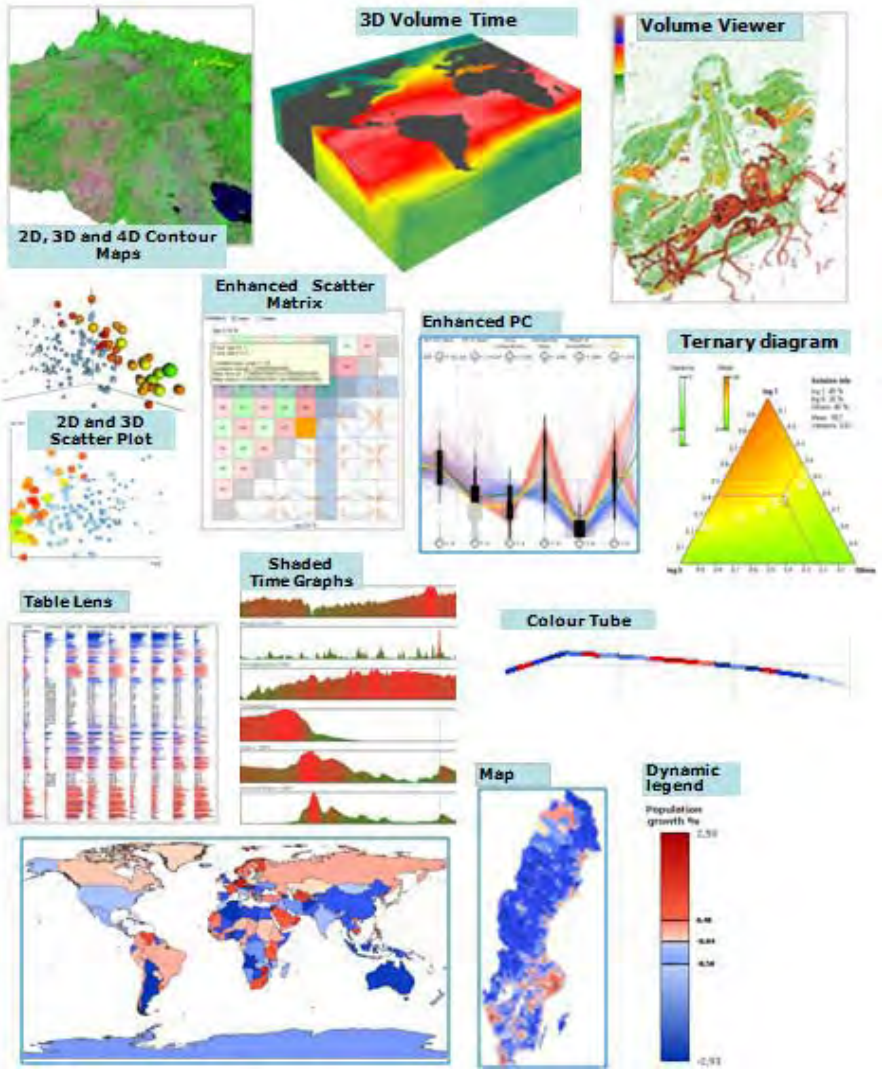
VISAD features include:

- Interaction methods that allow the involvement of the user in the fusion process, data exploration and knowledge discovery;
- Visualization of large data sets: patterns, trends, changes over time, outliers, exceptions, anomalies, relationships, correlations, clusters, groups, context, etc;
- Visualization of uncertainty, reliability, completeness and quality of information;
- Visualization of different levels of abstraction or granularity (in time and space).

One initial application is maritime anomaly detection and situation awareness.

Visual Soph: **Y/N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collab: **N?**
Potential Maritime Application: What is Normal Behaviour, Sensor Datastream, Intellipedia Connections, Wide Area Surveillance, Surveillance Coverage.				
Vendor: University of Skövde			**Video:** None	
References: [39] [108]				

Table 5-6 GeoAnalytics Visualization (GAV)



GAV is a visualization toolkit with components that support a mixture of technologies from the three data visualization fields: information visualization, geovisualization, and scientific visualization. GAV renders the visualizations using Flash. It has a layered-components architecture, multiple-linked and coordinated views, dynamic classified focus and context maps, and parallel coordinates plot. Although it provides complex visualization, it may not be true visual analytics because (based on the descriptions in the papers) it does not allow the operator to insert insights into an emerging model.

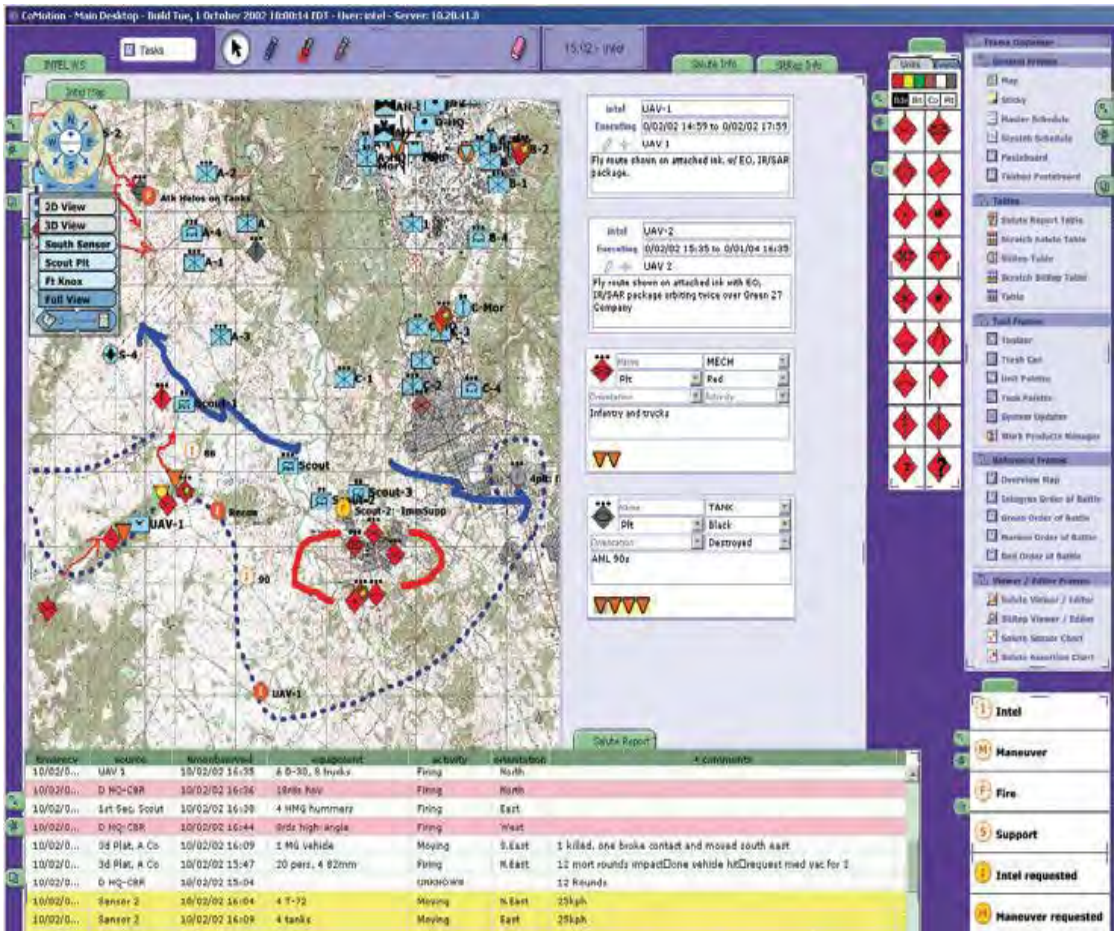
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **N?**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Sensor Datastream, Intellipedia Connections, Surveillance Coverage, Special Event

Vendor: University of Skövde	**Video:** None

References: [54, 70-71]

Table 5-7 Command Post of the Future



The Command Post of the Future is an executive level decision support system providing situational awareness and collaborative tools to support decision making. This tool suite is built using General Dynamics C4 Systems CoMotion technology. CoMotion supports visualization, information analysis, and collaboration, in a single, integrated environment that ultimately helps commanders and decision makers analyze information, share thoughts, and evaluate courses of action.

- Team members collaborate to create a multi-perspective shared operational picture.
- Supports parallel, synchronous and asynchronous cross functional planning and execution.
- Allows analysts to tailor visualizations to suit how they absorb information, thus allowing others to see what they are thinking.

Brochures suggest that it supports a relatively small group of visualization options, which would be appropriate for its goals and end-user needs.

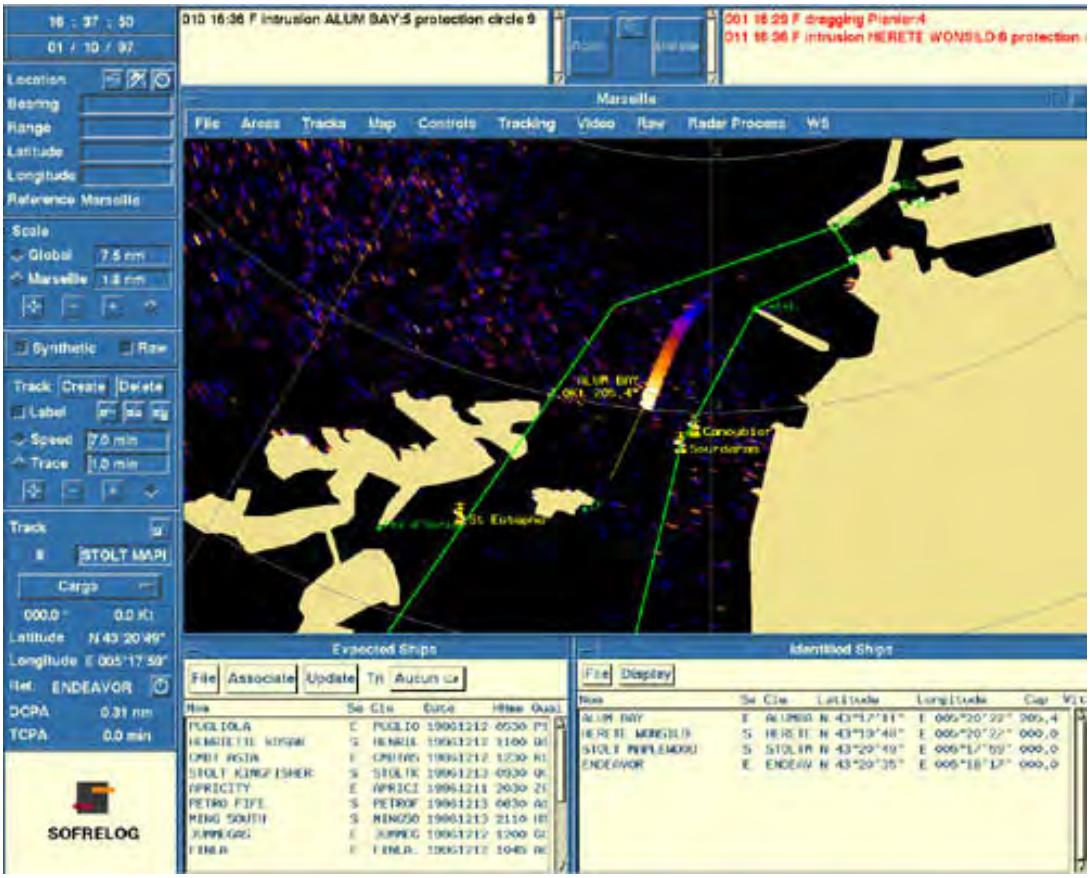
Visual Soph: **N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collaborative: **Y**

Potential Maritime Application: What is Normal Behaviour, Wide Area Surveilance, Surveillance Coverage, Special Event

Vendor: General Dynamics	**Video:** None

References: [46]

Table 5-8 Sofrelog



Superimposed raw radar images from multiple radars are displayed, automatically selects the best sensor input to track each vessel, shadows for one sensor are automatically filled-in by other sensors. Customizable event alarm structure. The entire tracking history of suspicious vessels can be displayed, showing place of origin, other vessels encountered. Future vessel position can be predicted based on current course and speed. Simulator and Training modes using archived incidence from your area.

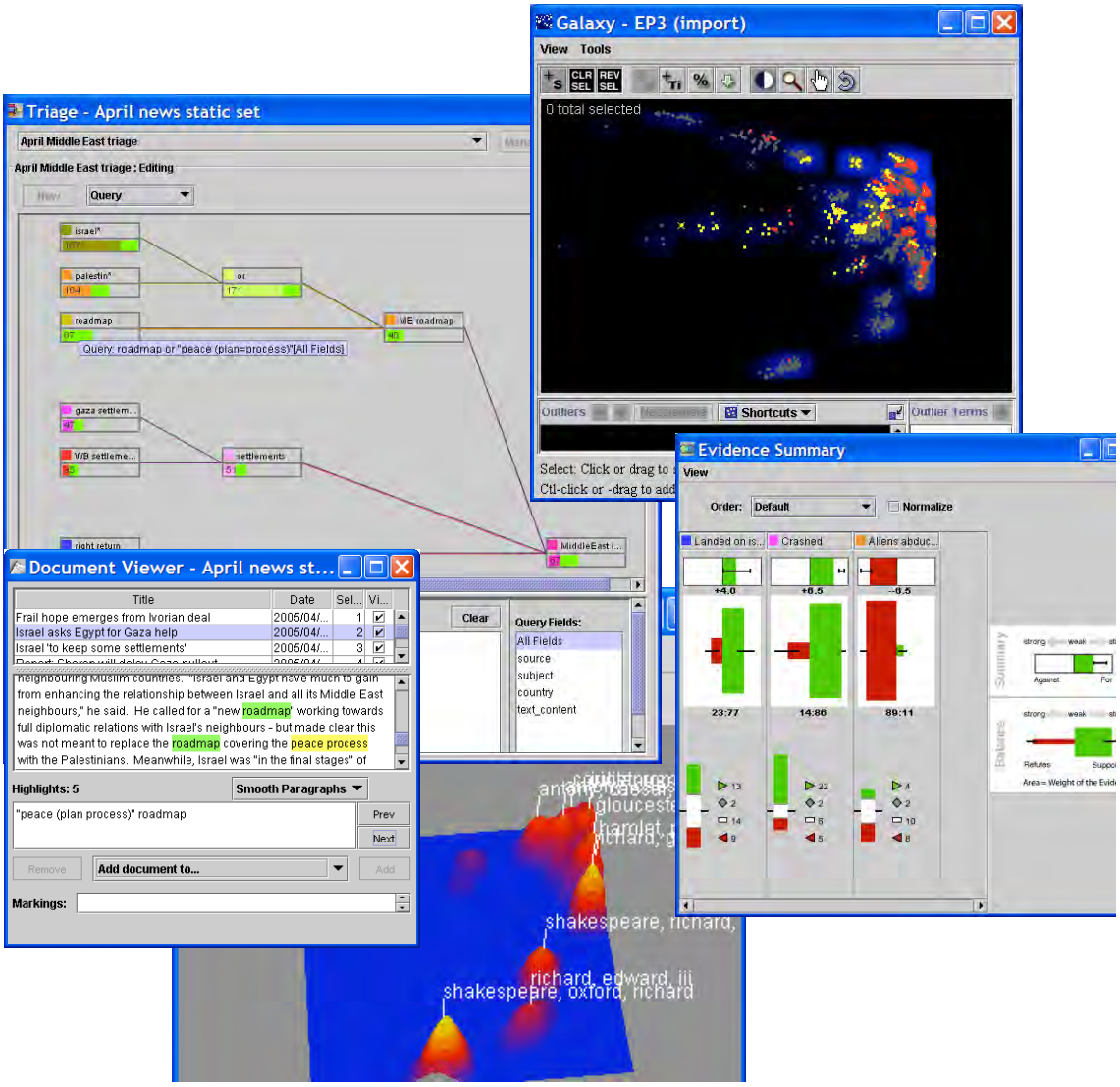
Visual Soph: **N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **?**	Collaborative: **Y**

Potential Maritime Application: Wide Area Surveillance, Surveillance Coverage, Special Event

Vendor: Sofrelog	**Video:**

References: [120]

Table 5-9 In-Spire



In-Spire is able to uncover relationships, trends, and themes hidden within textual data, and thus create new knowledge and new insights that could be used to assess terrorist threats, determine how to treat a medical condition, or gather market research on the competition. It provides visual interfaces for: reading similar documents together, removing less interesting clumps, finding relevant information, keeping track of what is found, inspecting non-hits among the hits, seeing time patterns, seeing correlations among groups, doing triage, managing evidence and hypotheses, summarizing evidence, removing unhelpful themes, finding similar documents.

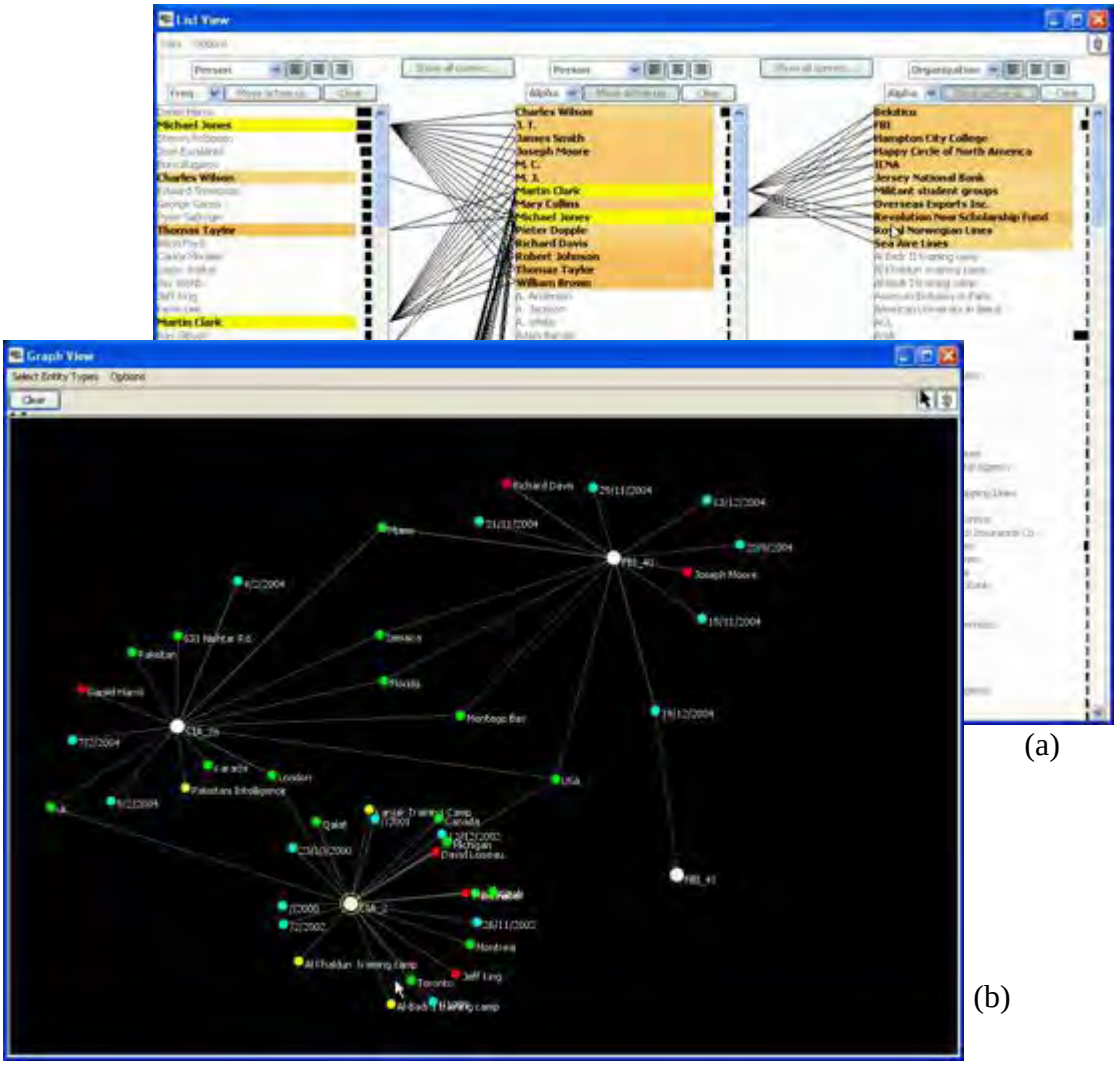
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Intellipedia, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: Pacific Northwest National Laboratory	**Video:** InSpire.avi

References: [100] [98]

Table 5-10 Jigsaw



Jigsaw is a suite of interconnected, cooperating, interactive visualizations that present multiple perspectives on a document collection and shows, in particular, connections between entities across the collection. It uses a fundamentally simple user interaction model in its views that make the system less complex for analysts to use. It is a working system that has already exhibited investigative value, winning the 2007 VAST Challenge contest ([47]). Views include: List view (a) Graph View (b), Scatter Plot View Document View, Calendar View, Document Cluster View, and Shoebox for evidence marshalling.

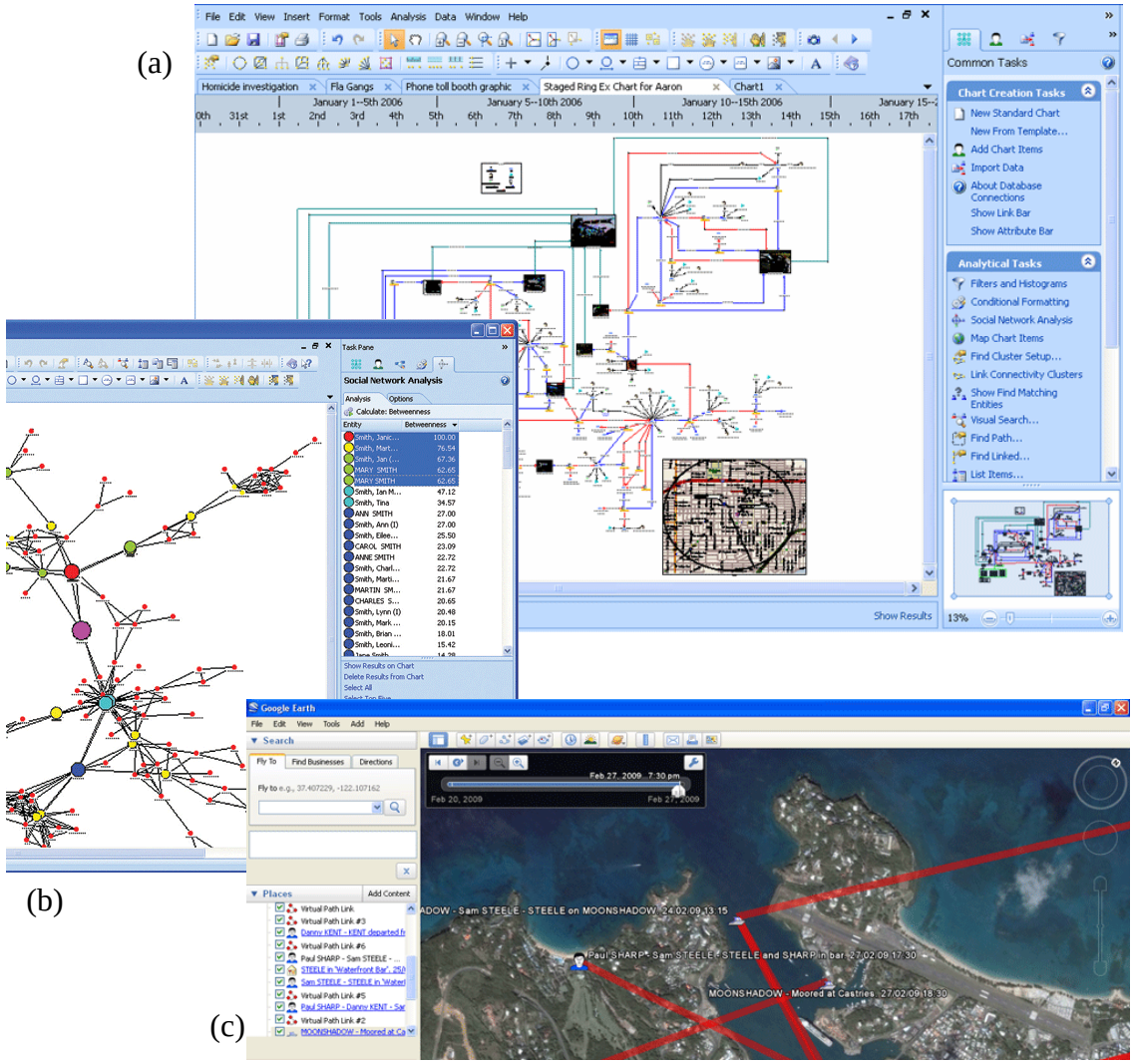
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Intellipedia, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: Pacific Northwest National Laboratory	**Video:** jigsaw_video.avi

References: [47, 124]

Table 5-11 Analyst's Notebook



Analyst's Notebook is engineered to help analysts quickly turn large sets of disparate data into high quality and actionable intelligence to prevent crime, fraud and terrorism. Capabilities include: create charts manually or automatically from structured data sources including databases, online data, spreadsheets; visualize and analyze (a) large volumes of raw, multi-format data to understand the who, what, when, where and why; view social patterns (b) and trends unfolding over time and hone in on key players and activities; quickly identify and understand key individuals in complex target networks; visualize geographical information (c), track movements of suspects over time, and communicate complex cases using intuitive briefing charts that capture and organize supporting data to tell the story.

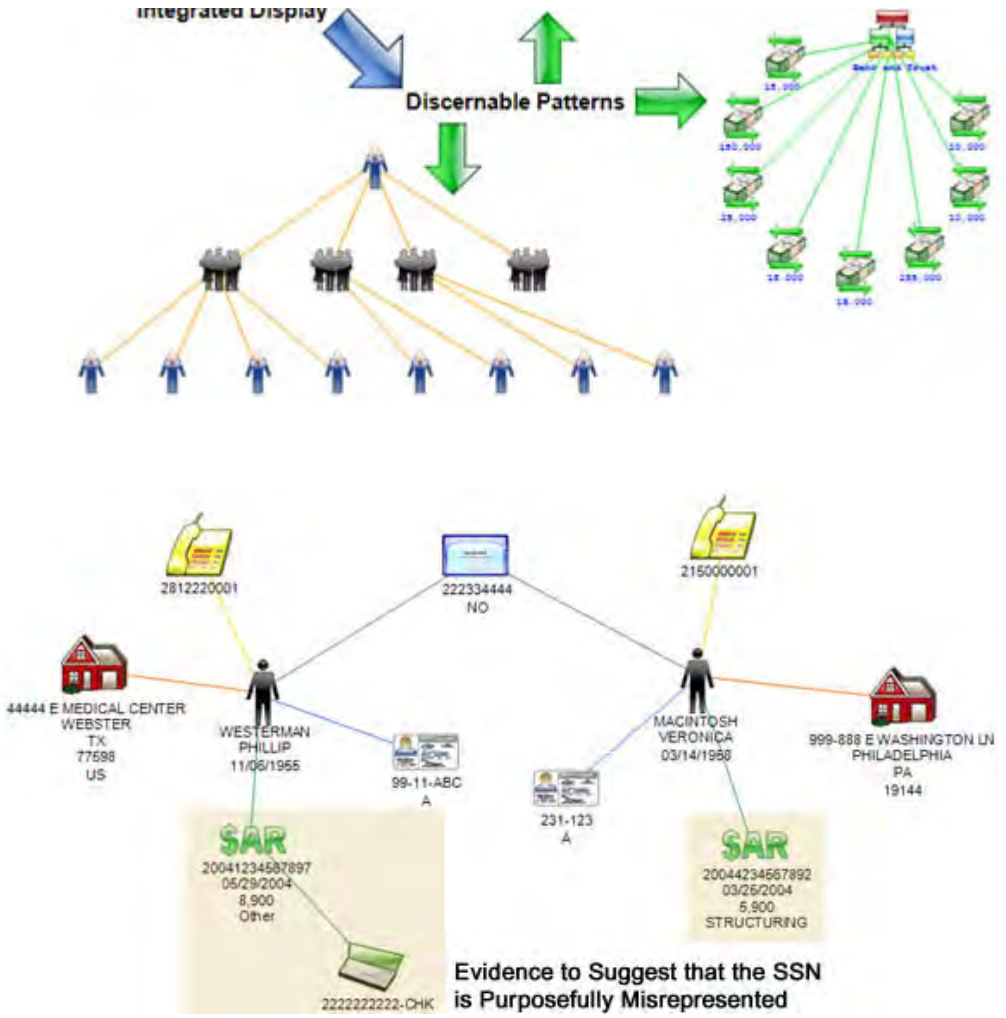
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y/N**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Intellipedia, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: I2 Inc.	**Video:**

References: [58]

Table 5-12 VisuaLinks



VisuaLinks is a platform-independent, graphical analysis tool used to expose hidden activity and behavioral patterns in any number and type of data sources. It uses graphical representations to uncover underlying relationships and patterns. VisuaLinks addresses the entire analytical process – query and display large amounts of data with no size limit, use one of many query algorithms to expose networks, patterns and trends in the data, visually reveal direct and indirect linkages within the data, perform proactive and reactive analysis supporting tactical and strategic operations, collaborate with peers sharing data and related analysis, prepare and print final analysis presentations including on Google Earth.

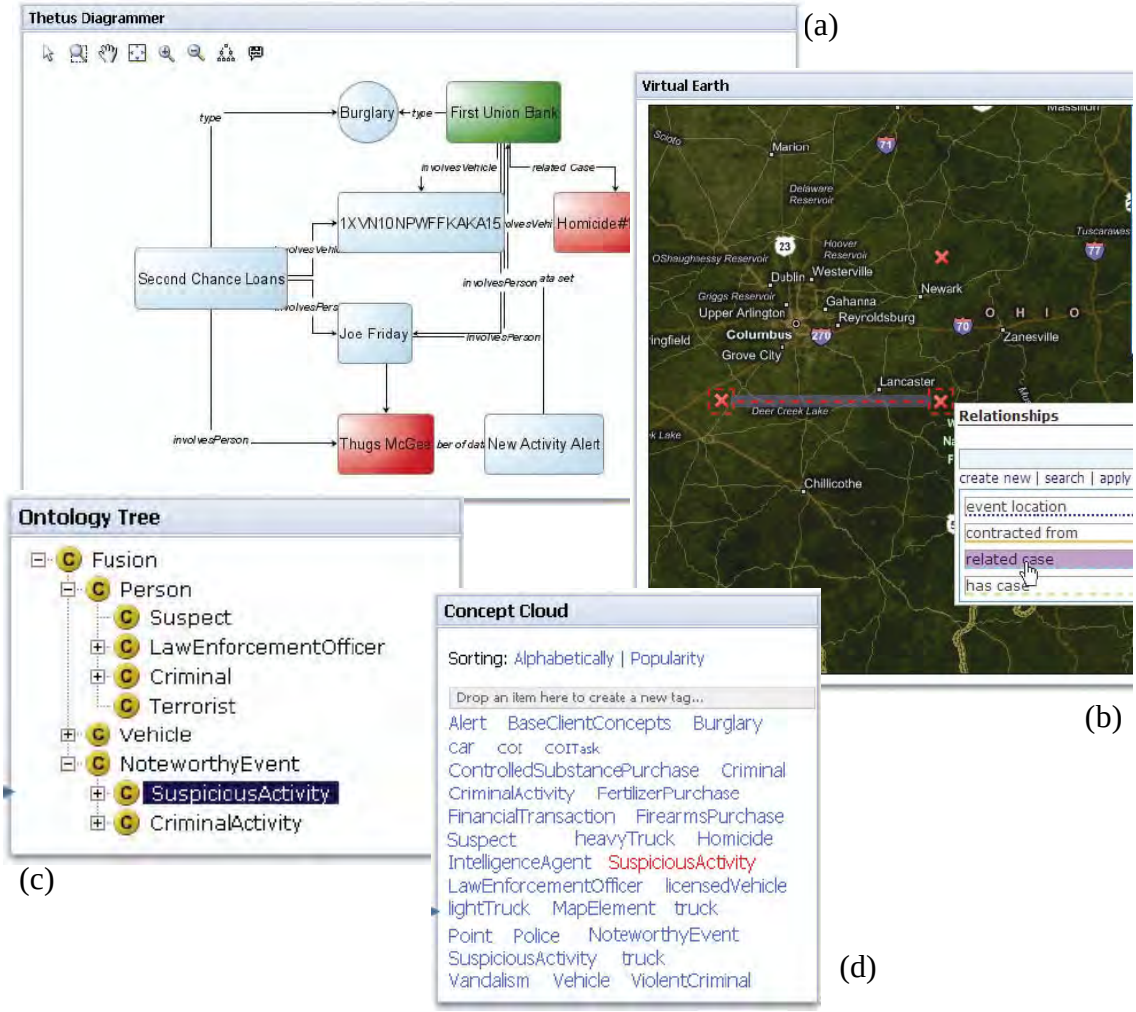
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Intellipedia, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: Visual Analytics Inc.	**Video:**

References: [138]

Table 5-13 Thetus Intelligence Fusion Platform



The Thetus Intelligence Fusion Platform is engineered to derive integrated intelligence from multi-source, multi-format data. Automated workflow components increase the speed and efficiency of accessing the data, building an interpretive "story," which may include a network diagram (a), a map (b), an ontology (c), or a concept cloud (d), and automatically assembling and publishing reports to specific stakeholders in a wide variety of formats. Users can create and analyze cause-and-effect scenarios in support of proactive threat identification and interdiction. Participating communities can search, access, and share information using the familiar language and context of their discipline while maintaining shared meaning across systems. Intelligence products and analysis processes are preserved for collaboration, reusability, and ongoing information enhancement. Collection management and dissemination across the entire system are restricted by policy controls.

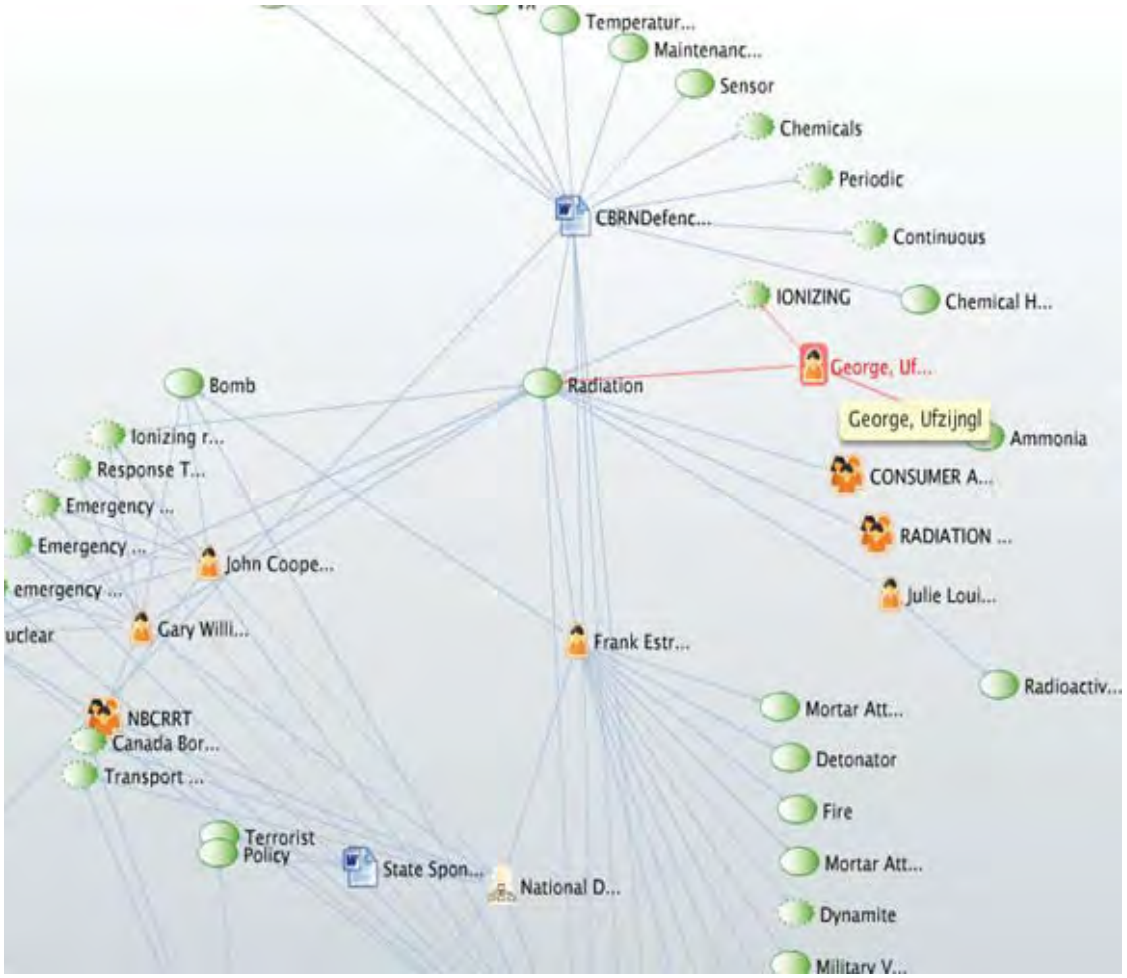
Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **Y**	Collaborative: **N?**

Potential Maritime Application: VOI Dossier, What is Normal Behaviour, Intellipedia, Knowledge Indexing, Text in Intelligence Reports, Special Event

Vendor: Thetus Inc.	**Video:**

References: [127-128]

Table 5-14 K-Mapper



KMapper provides a navigable visualization of an extended information space, including human resources, knowledge assets, procedural information, and conceptual information. It is thus a sophisticated and interactive visualization supporting exploration. The tool does not currently offer any capability for an analyst to build a model or tell analytical "story" so this does not qualify as visual analytics according to rule (2-5).

Visual Soph: **Y**	Interactive: **Y**	Exploratory: **Y**	Analytical: **N**	Collaborative: **N**

Potential Maritime Application: Knowledge Indexing

Vendor: DRDC Valcartier	**Video:**

References: [81]

Table 5-15 3D Multi-Touch Table

This 3D Touch Table, demonstrated at the 2005 ESRI conference, supports multiple simultaneous users and has an internal mechanism that enables it to deform into software-defined 3d structures. The table – top is covered in silicone. and when the table is told that it shall project heights, for example from Google Earth, it raises small plastic sticks from underneath the elastic silicone skin, and thereby 'real mountains' can rise from the table. (explanation is from http://velvetgrass.blogspot.com/2007/04/3d-terrain-touch-table-screen.html). The scene is projected onto the surface from above.

As the ocean has no elevation, it is not clear that this would be a significant advantage for the Navy.

Visual Soph: **Y/N**	Interactive: **Y**	Exploratory: **Y**	Analytical: **N**	Collaborative: **Y**

Potential Maritime Application: VOI Dossier and Track, What is Normal Behaviour, Wide Area Surveillance, Surveillance Coverage, Special Event

Vendor: San Diego State University,	**Video:**

References: [115]

Table 5-16 Assessment Wall

The Assessment Wall is a large-format wall display and software designed to help users more easily monitor and explore continually updating text sources such as news or reports, through a high-resolution touch-screen interface. The goal is to help users find the latest on topics known to be of interest along with emergent and unexpected themes. Additional interactivity allows discovery of relationships and patterns, all in context of the broader streaming data. The current version of the Assessment Wall is available as part of IN-SPIRE.

Visual Soph: **?**	Interactive: **?**	Exploratory: **?**	Analytical: **?**	Collaborative: **Y**

Potential Maritime Application: Hardware: VOI Dossier and Track, Wide Area Surveillance, Surveillance Coverage, Special Event. With IN-SPIRE: see Table 5-8.

Vendor: Pacific Northwest National Lab	**Video:**

References: [99]

THIS PAGE INTENTIONALLY LEFT BLANK

A ACRONYMS

3D	Three Dimensional
ACE	Attribute Correction Engine
ACM	Association for Computing Machinery
AI	Artificial Intelligence
AIS	Automatic Identification System
ARMAD	Automated Reasoning for Maritime Anomaly Detection
AVIZ	Analysis and Visualization
CAD	Computer Aided Design
CCI	Command, Control, & Interoperability
CERATOPS	Center for the Extraction and Summarization of Events and Opinions in Text
CF	Canadian Forces
CKID	Center for Knowledge Integration and Discovery
CMV	Coordinated and Multiple Views
CNVAC	Canadian National Visualization and Analytics Center
COEs	Centers of Excellence
Cdr	Commander
CORA	Centre for Operational Research and Analysis
DB	Database
DHS	Department of Homeland Security
DND	Department of National Defence
DRDC	Defence Research and Development Canada
DyDAn	Center for Dynamic Data Analysis

ENVI	Environment for Visualizing Imagery
ESRI	Environmental Systems Research Institute
FODAVA	Foundations on Data Analysis and Visual Analytics
GAV	GeoAnalytics Visualization
GI Science	Geographic Information Science
HSIP	Homeland Security Infrastructure Program
IAIS	Institut für Intelligente Analyse- und Informationssysteme
IDS	Institute for Discrete Sciences
IEEE	Institute of Electrical and Electronic Engineers
IGD	Institute for Computer Graphics Research in Darmstadt
IJVAAIM	International Journal of Visual Analytics for Advanced Information Management
ILOG	An IBM Company in Gentilly, France (no published acronym explanation)
INRIA	Institut national de recherche en informatique et automatique
LIDAR	Light Detection and Ranging
MDACIV	Maritime Domain Analysis through Collaboration and Interactive Visualization
MIAS	Multimodal Information Access and Synthesis
MSPA	Maritime Security Patrol Area
MUSIC	Multi-Sensor Integration within a Common Operating Environment
NDV	N-Dimensional Visualizer
NEVAC	North-East Visualization and Analytics Center
NSF	US National Science Foundation
NVAC	National Visualization and Analytics Center
PARVAC	Pacific Rim Visualization and Analytics Center
PNNL	Pacific Northwest National Laboratory
PURVAC	Purdue University Regional Visualization and Analytics Center
RAT	RMP Analysis Toolset
RJOC	Regional Joint Operations Centre
RMP	Recognized Maritime Picture
SCIENCE	Spatial Cognition and Interactive Expertise in Natural and Computational Environments
SFU	Simon Fraser University
SIGKDD	Special Interest Group on Knowledge Discovery and Data Mining

SPIE	Society of Photo-Optical Instrumentation Engineers
SRVAC	Southeastern Regional Visualization and Analytics Center
TVCG	Transactions on Visualization and Computer Graphics
UBC	University of British Columbia
UNITAR	UN Institute for Training and Research
UNOSAT	UNITAR Operational Satellite Applications Programme
US	United States
VA	Visual Analytics
VAC	Visual Analytics Consortium
VACCINE	Visual Analytics for Command, Control, and INteroperability Environments
VAKD	Workshop on Visual Analytics and Knowledge Discovery
VAMA	Visual Analytics for Maritime Awareness
VAR	Visual Analytics Research Lab at SFU
VAST	Visual Analytics Science and Technology
VISAD	Visualization for Algorithm Development
VOI	Vessel of Interest
VR	Virtual Reality

THIS PAGE INTENTIONALLY LEFT BLANK

B ANNOTATED BIBLIOGRAPHY

[1] ACM Special Interest Group on Knowledge Discovery and Data Mining (SIGKDD), *SIGKDD Explorations Special Issue: Visual Analytics*, http://www.sigkdd.org/explorations/issue.php?volume=9&issue=2&year=2007&month=12, 2007. [*See file:* ACM SIGKDD Explorations Special Issue.mht]

This is an example of a Non-VA Journal publishing a Visual Analytics special issue.

[2] W. Aigner, "Visualization of time-oriented data visualization techniques," http://ieg.ifs.tuwien.ac.at/~aigner/presentations/TimeViz_techniques0809_1up.pdf, 2009. [*A copy is attached as file:* AignerTimeViz.pdf]

Very interesting and useful ideas on how to visualize time-varying data.

[3] G. Andrienko, and N. Andrienko, "Exploration of Massive Movement Data: a Visual Analytics Approach," in AGILE, Girona Spain, 2008. [*A copy is attached as file:* AndrienkoAgile08.pdf]

[4] G. Andrienko, and N. Andrienko, "Spatio-temporal aggregation for visual analysis of movements," in Visual Analytics Science and Technology, 2008. VAST '08. IEEE Symposium on, 2008, pp. 51-58.

An important paper on ways to visualize and explore the statistical patterns in vessel motion. Are there, for example, whole clusters of vessel that travel up the St. Lawrence Seaway?

[5] G. Andrienko, N. Andrienko, P. Jankowski *et al.*, "Geovisual analytics for spatial decision support: Setting the research agenda," *International Journal of Geographical Information Science*, vol. 21, no. 8, pp. 839–857, September 2007, http://infovis.uni-konstanz.de/papers/2007/VisualGeoAnalytics_VASDS-IJGIS2007.pdf, 2007. [*A copy is attached as file:* Andrienko_GeoVisualAnalytics.pdf]

This agenda-setting paper makes the argument that GeoVisual Analytics should be a recognized subtype of visual analytics. It highlights the following challenges of geospatial visual analytics: complex nature of geographic space, multiple actors with different roles (hence a need for collaboration, communication, and flexibility), and tacit criteria and knowledge.

[6] G. Andrienko, N. Andrienko, and S. Wrobel, "Visual Analytics Tools for Analysis of Movement Data," in ACM SIGKDD Explorations http://geoanalytics.net/and/papers/sigkdd07.pdf, 2007, pp. 38-46. [*A copy is attached as file:* AndrienkoSigkdd07.pdf]

A useful paper exploring ways to visualize repeated motion patterns, using multiple linked displays. Introduces visualizations that key on daily and weekly patterns, but also allow you to extract and view a single trip, linked to a sliding time filter.

[7] *ACM SIGKDD Workshop on Visual Analytics and Knowledge Discovery*, http://portal.acm.org/toc.cfm?id=1562849&type=proceeding&coll=Portal&dl=GUIDE&CFID=54542277&CFTOKEN=77900280, 2009.
[*See file:* VAKD09.mht]

[8] K. D. Bailey, *Typologies and Taxonomies: An Introduction to Classification Techniques* p.^pp. 96: Sage Publications, Inc, 1994.

A useful monograph about classification schemes.

[9] P. Bak, F. Mansmann, H. Janetzko *et al.*, "Spatiotemporal Analysis of Sensor Logs using Growth Ring Maps," in Visual Analytics Science and Technology, Atlantic City, New Jersey, IEEE, http://infovis.uni-konstanz.de/papers/2009/bak.pdf, 2009.
[*A copy is attached as file:* bakGrowthRings.pdf]

This paper is marked "visual analytics" but is really just a visualization strategy. It shows a way to visually summarize long-term time patterns of activity using "growth rings."

[10] V. Barash. "Excel .Net Map," web page at: http://www.socialtext.net/ocu2008/index.cgi?excel_net_map_sna_toolkit, 2008.

Relationships are edges in a directed map. Nodes are individuals and are shown as tagged semi-transparent bubbles, with size indicating some parameter. The thing of interest is the creative spacing of the bubbles into a sort of ring galaxy. This is not Visual Analytics, rather visualization, but the portrayal might be useful in a VA solution.

[11] B. Beaulieu, "Homeland Security through the Palanterra," *GeoIntelligence*, pp. 14-19, July/August 2004, http://www.nima.mil/NGASiteContent/StaticFiles/OCR/Geo0704.pdf, 2004.
[*A copy is attached as file:* Palenterra.pdf]

[12] E. Bertini, and D. Lalanne, "Surveying the complementary role of automatic data analysis and visualization in knowledge discovery," in VAKD'09, Paris, http://www.hiit.fi/vakd09/vakd09bertini-cr.pdf, 2009. [*A copy is attached as file:* Bertini_VAKD_09.pdf]

Makes the argument that data visualization and data mining need to be better integrated.

[13] M. Bloch, and S. Carter. "Twitter Chatter During the Super Bowl," web page at: http://www.nytimes.com/interactive/2009/02/02/sports/20090202_superbowl_twitter.html, 2009. [*A copy is attached as file:* SuperBowlTweets.png SuperbowlTwitter.avi]

Uses word clouds to show what people were tweeting during the Superbowl. The data can be visualized in three dimensions: geograhically (words are superimposed on a map of the USA),

temporally (the viewer moves back and forth in time using a slider across the top of the page, and word clouds change instantly), and by subject (by clicking on a menu down the top left side). Users can drill-down to see exact word-counts by mousing-over a city or region.

[14] E. K. Bowman, D. Gouin, P. Houghton *et al.*, "Intense Collaboration: Knowledge Integration Task (KnowIT) Results," TR-C3I-TP2-1-2008, TTCP C3I Group; Technical Panel 2 2008.
[*A copy is attached as file:* Intense Collaboration KnowIT report Aug 14 (2).doc]

Lays out the management methodologies and team interaction standards to be used when scientific teams from different agencies and different allied countries have to work together intensely.

[15] S. E. Brennan, K. Mueller, G. Zelinsky *et al.*, "Toward a Multi-Analyst, Collaborative Framework for Visual Analytics," in IEEE Symposium On Visual Analytics Science And Technology (VAST 06) IEEE, http://www.psychology.sunysb.edu/sbrennan-/papers/VAST.pdf, 2006.
[*A copy is attached as file:* Brennan_CollabFramework.pdf]

The paper sketches a method by which multiple analysts build and maintain separate analytical models and visualizations, but may at any time super-impose a connected view of the analytical models of another analyst. Views are node-maps, where common-ground might be for example common data points used.

[16] B. Brewin, "Intelligence Community Developing a Virtual World for Analytics," *Government Executive .com*, Nove 7 2007, http://www.virtualworldsnews.com/2007/11/intelligence-co.html#more, 2007.
[*A copy is attached as file:* A-SpaceX.mht]

This is a brief article mentioning a US project Analyst Space for Exploitation (A-SpaceX) aimed at exploiting virtual worlds for information analysis. Jeffery Morrison, who runs the program, wants to build in visual metaphors for information that he calls "mind snaps." The article suggests "virtual worlds could be golden for the future of predictive analysis."

[17] B. Brown, "Intelligence community developing virtual world analysis tools," *Government Executive*, November 7, 2007 http://www.govexec.com/dailyfed/1107/110707bb1.htm, 2007.
[*A copy is attached as file:* Brown_A-SpaceX.mht]

A brief magazine article about A-SpaceX, introducing the plan to create virtual worlds where analysts can explore intelligence questions.

[18] "Hierarchical multi-touch selection techniques for collaborative geospatial analysis," http://link.aip.org/link/?PSI/7346/73460D/1, http://dx.doi.org/10.1117/12.819025, 2009.
[*See file:* ButkiewiczMultiTouch.pdf]

The multi-touch table was found to be "powerful, but non-intimidating; a system that allows and encourages complex combinations of actions, but can be operated without any training."

[19] S. Butner, W. Cowley, V. Crow *et al.*, "A Look at First Look," *VAC Views*, pp. 14-15, November 2008, 2008. [*A copy is attached as file:* VACViews05_nov08.pdf]

First Look monitors information streams and comments to the operators when elements of the information streams change.

[20] C. E. Carlsen. "Metasyn Interactive information visualization," web page at: http://sixthsensor.dk/work/6, 2008. [*A copy is attached as file:* Larsen_Metasyn]

This is a good technical summary of how Carlsen conceptualized Metasyn, using three levels: Meta, Mesa, and Micro. It also includes three screen-shots that are helpful. The installation was on a very large curved screen.

[21] C. E. Carlsen, and SixthsensorStream, "Metasyn," Youtube Video available on-line at: http://www.youtube.com/watch?v=RXJuJnEHc1Y, 2009.
[*A copy is attached as file:* metasyn_video.mp4]

An interesting "3D World" visualization of a corpus of art. Interesting features include: lines that show links between related objects, but that fade into the distance, navigation abilty so that lines fade or defade, leaving the forground clear, different types of links are different colours, you can drill down on each node.

[22] CERATOPS. "Center for the Extraction and Summarization of Events and Opinions in Text " web page at: http://www.cs.pitt.edu/mpqa/ceratops/, 2009.
[*A copy is attached as file:* CERATOPS Home Page.mht]

CERATOPS looks for subtle information such as opinions and beliefs in free text.

[23] S.-M. Chan, L. Xiao, J. Gerth *et al.*, "Maintaining interactivity while exploring massive time series," in Visual Analytics Science and Technology, 2008. VAST '08. IEEE Symposium on, 2008, pp. 59-66.

Because visual analytics required real-time responsiveness from the computer, systems accessing huge amounts of data must be implemented innovatively. This is one example of such an architecture.

[24] C. Chen, "An Information-Theoretic View of Visual Analytics," *Computer Graphics and Applications, IEEE,* vol. 28, no. 1, pp. 18-23, 2008.
[*A copy is attached as file:* Chen06.pdf]

Provides theoretical guidelines for designing visual analytic systems so that the visualizations are not deceptive.

[25] Y. Chen, J. Yang, and W. Ribarsky, "Toward effective insight management in visual analytics systems," in Visualization Symposium, 2009. PacificVis '09. IEEE Pacific, 2009, pp. 49-56.

The paper lays out a knowledge management methodology that should (it suggests) work in parallel to the visualization, as part of the visual analytics.

[26] CNVAC. "Canadian Network of Visual Analytics Centres," web page at: http://www.cnvac.ca/, 2008.
[*A copy is attached as file:* CnvacHomePage.mht]

A rather thin front-page for the Canadian network of visual analytics centres.

[27] M. Davenport, "Maritime Domain Awareness Knowledge Management Requirements," CR 2007-174, DRDC-Valcartier, 2007.

An analysis of potential requirements for knowledge management capabilities, at the RJOCs.

[28] M. Davenport, "MISR-Vis Maritime Intelligence, Surveillance, and Reconnaissance Knowledge Base," CR 2007-543, DRDC Valcartier, 2007.

Describes the development of an ontology of visualization strategies and their potential application to maritime domain awareness.

[29] M. Davenport, "Maritime Anomaly Detection Workshop Report and Analysis," CR 2008-275, DRDC-Valcartier, 2008.

Reports on a workshop held in Valcartier in 2008 with subject-matter experts from RJOC(A), in which a set of maritime anomalies was brainstormed and refined. Provides a taxonomy of 37 anomalies.

[30] M. Davenport, *Opportunities for Applying Visual Analytics for Maritime Awareness*, 2009.

[31] M. Davenport, "Opportunities for Applying Visual Analytics for Maritime Awareness," CR 2009-227, DRDC-Valcartier, 2009.

This is the second of two reports under the Visual Analytics for Maritime Awareness contract.

[32] M. Davenport, and C. Risley, "Information Visualization: the State of the Art for Maritime Domain Awareness," CR 2006-122, DRDC Atlantic, http://pubs.drdc-rddc.gc.ca, 2006.

An extensive survey of research and commercial software and hardware that is of relevance to visualization of the maritime domain.

[33] M. Davenport, E. Widdis, and J. Rafuse, "RMP Baseline Update, Vols 1-3," TR 2005-293, TR 2005-294, TR 2005-295, DRDC-Atlantic, 2005.

An inventory of surveillance assets and surveillance data processing methods, done as a foundation for the MUSIC project.

[34] *Third Annual DHS University Network Summit*, http://www.orau.gov/DHSsummit/program.pdf, 2009. [*See file:* DhsUniversityNetworkSummit2009.pdf]

This appears to be a team-building workshop rather than an academic conference. There are apparently no proceedings published.

[35] DHS Science and Technology Directorate, "Five-Year Research and Development Plan; Fiscal Years 2008-2013," H. Security, ed., Department of Homeland Security, http://www.dhs.gov/xlibrary/assets/SandT5yearplan.pdf, 2008.
[*A copy is attached as file:* DhsSandT5yearplan.pdf]

Shows the US Department of Homeland Security Science and Technology goals and budget for the next five years (about US$4.5M per year for basic VA research, plus about US$3M per year for university centers of excellence in Command, Control, and interoperability (CCI))

[36] DyDAn. "The Homeland Security Center for Dynamic Data Analysis " web page at: http://dydan.rutgers.edu/, 2009.

Announcement of the creation of DyDAn at Rutgers, with an overview of its mission.

[37] S. Eaton, "Visualization and Analytics Centers," *VAC Views*, pp. 20-27, Nov 2008, 2008. [*A copy is attached as file:* VACViews05_nov08.pdf]

A useful list of all the VAC consortium members as of 2008, with brief notes on what research they are doing.

[38] J. A. Fails, A. Karlson, L. Shahamat *et al.*, "A Visual Interface for Multivariate Temporal Data: Finding Patterns of Events across Multiple Histories," in Proceedings of IEEE Symposium on Visual Analytics Science and Technology (VAST 2006), IEEE, http://research.microsoft.com/pubs/75850/fails-VAST2006.pdf, 2006, pp. 167-174. [*A copy is attached as file:* Fails_PatternFinder.pdf]

Provides one way to overlay extended-time events, in this case medical drug interactions as a function of period of medication. Much of their discussion is looking at how to display tabular data (text) in small tables associated with events. Events are plotted on a horizontal time-line.

[39] G. Falkman, T. Ziemke, and M. Riveiro. "Information visualization for ground situation awareness," web page at: http://www.his.se/english/research/infofusion/research/scenarios-and-projects/gsa/gsa2-visualization/, 2009. [*A copy is attached as file:* VisadPage.mht]

Shows the architecture of VISAD: an interactive and visual analytical tool for the detection of behavioral anomalies in maritime traffic data. This includes: including the user in the fusion process. visualization of large data sets, visualization of uncertainty, and different levels of granularity in time and space.

[40] S. Few, "Visualizing Change: An Innovation in Time-Series Analysis," SAS, www.jmp.com/few, 2007. [*A copy is attached as file:* Few_visualizing_change.pdf]

[41] B. Fisher, "VACCINE: Visual Analytics for Command, Control, and INteroperability Environments," Simon Fraser University, 2009. [*A copy is attached as file:* SFU_VACCINE.pdf]

Our best description (so far) of the new VACCINE organization for visual analytics.

[42] D. Fisher, A. Hoff, G. Robertson *et al.*, "Narratives: A visualization to track narrative events as they develop," in Visual Analytics Science and Technology, 2008. VAST '08. IEEE Symposium on, http://research.microsoft.com/apps/pubs/default.aspx?id=78917, 2008, pp. 115-122. [*A copy is attached as file:* FisherNarratives.pdf]

A text-analysis tool that looks for themes and associated keywrds, and then tracks how those keywords evolve over time.

[43] FODAVA. "NSF/DHS FODAVA-Lead: Foundations of Data and Visual Analytics," web page at: http://fodava.gatech.edu/, 2009. [*A copy is attached as file:* Welcome to FODAVA.mht]

FODAVA is the newly-set-up organization based at Georgia Tech, operating with funding from the National Science Foundation and the Department of Homeland Security

[44] Future Point Systems Inc., "Starlight Demo - Text and UAV Video Analysis," Youtube available on-line at: http://www.youtube.com/watch?v=dUtv1b8cPqo&NR=1, 2008.
[*A copy is attached as file:* YouTube - Starlight and UAVs.mht]

This video is quite recent, and walks through a scenario in Afghanistan, assembling new reports of rocket attacks on airports and cross-referencing to available UAV flights. Useful for seeing the CONOPS of Starlight and the interactions with the software.

[45] Future Point Systems Inc. "Products: Starlight," web page at: http://www.futurepointsystems.com/?page=products, 2009.
[*A copy is attached as file:* StarlightHomepage.mht]

Starlight is an early and still leading visual analytics software suite. It can portray network diagrams, free-topic clusters of words, geospatial relationships, temporal relationships, and hierarchical models in an abstract analysis space, with links to maps, photos, text documents, etc.

[46] General Dynamics, "Command Post of the Future," G. Dynamics, ed., http://www.gdc4s.com/documents/cpof-9-12-06.pdf, 2006.
[*A copy is attached as file:* Cpof_Brochure.pdf]

This is the quick introduction to the features of Command Post of the Future, which is mentioned in Illuminating the Path.

[47] Georgia Tech. "Sample Detailed Answer (extracted from the VAST 2007 contest entry submitted by Georgia Tech)," web page at: http://www.cs.umd.edu/hcil/VASTchallenge08/ExamplefromVAST2007contest-GT-Jigsaw/index.htm, 2007.
[*A copy is attached as file:* JigsawGeorgiaTech.mht]

This summary of the winning Jigsaw entry into the VASt 2007 "Blue Iguanadon" contest serves as a good introduction to the Jigsaw tool, complete with some frank comments on what capabilities they need but don't yet have.

[48] Georgia Tech. "Visual Analytics Digital Library," web page at: http://vadl.cc.gatech.edu/, 2009. [*A copy is attached as file:* Visual Analytics Digital Library.mht]

This is mainly a collection of lecture notes and homework assignments from the Georgia Tech center of excellence.

[49] M. Ghoniem, D. Luo, J. Yang *et al.*, "NewsLab: Exploratory Broadcast News Video Analysis," CVC-UNCC-07-11, UNC Charlotte, http://www.viscenter.uncc.edu/TechnicalReports/CVC-UNCC-07-11.pdf, 2007.
[*A copy is attached as file:* NewsLab.pdf]

Uses a river metaphor is used to depict the thematic changes of the news over time, together with a lens for drilling-down for details. Data is extracted from the closed captions on the TV new casts. Can be used to find emerging topics in the news, compare different broadcasters, or mine the news for topics of interest.

[50] I. Global, *International Journal of Visual Analytics for Advanced Information Management (IJVAAIM)*, http://www.igi-global.com/journals/details.asp?id=8084, 2010.
[*See file:* IJVAAIM.mht]

This journal is just starting up, but could be important as the first journal (VAC Views is a magazine, not a journal) dedicated to visual analytics.

[51] A. Godwin, R. Chang, R. Kosara *et al.*, "Visual analysis of entity relationships in the Global Terrorism Database," SPIE, http://link.aip.org/link/?PSI/6983/69830G/1 http://dx.doi.org/10.1117/12.778084, 2008, pp. 69830G.

Uses algorithms from gene sequencing to find matches between patterns of activity of terrorist groups, thus identifying probable collaborations, and possibly attributing previously unattributed actions.

[52] M. C. Hao, U. Dayal, and D. A. Keim, "Visual analytics techniques for large multi-attribute time series data," in Visualization and Data Analysis 2008, SPIE, http://infovis.uni-konstanz.de/papers/2008//EI108-EI107-32Submit.pdf, 2008, pp. 680908.
[*A copy is attached as file:* HaoTimeSeries.pdf]

Transforms a very large multi-attribute time series into a series of coloured icons, with the shape of the icons encoding the multiple attributes so that changes over time can be seen visually.

[53] M. C. Hao, U. Dayal, D. A. Keim *et al.*, "Visual analytics of anomaly detection in large data streams," SPIE, http://link.aip.org/link/?PSI/7243/72430B/1, http://dx.doi.org/10.1117/12.810945, 2009, pp. 72430B.

This is mainly a presentation of ways to detect and display anomalies in massive data streams. Not much of an anaytical tool.

[54] Q. Ho, and M. Jern, "Exploratory 3D Geovisual Analytics," in Research, Innovation and Vision for the Future, 2008. RIVF 2008. IEEE International Conference on, 2008.

Describes the GeoAnalytics Visualization component toolkit, using many example from maritime surveillance. The toolkit is able to represent patterns in geography amd time, as well as attribute spaces.

[55] J. Hollan, E. Hutchins, and D. Kirsh, "Distributed cognition: toward a new foundation for human-computer interaction research," *ACM Trans. Comput.-Hum. Interact.*, vol. 7, no. 2, pp. 174-196, http://portal.acm.org/citation.cfm?doid=353485.353487#, 2000.
[*A copy is attached as file:* hollanDistributedCog.pdf]

A seminal paper on the cognitive science behind visual analytics, and on new paradigms for thinking of collaboration.

[56] Homeland Security, "Homeland Security Presidential Directives," H. Security, ed., http://www.dhs.gov/xabout/laws/editorial_0607.shtm, 2009.
[*A copy is attached as file:* DHS Homeland Security Presidential Directives.mht]

A list of 24 presidential directives that serve as a mandate for DHS. Directives 3, 5, 7, 8, 9, 10, 21, 23 are directly relevant to visual analytics.

[57] E. Hovy, P. Pantel, and D. McLeod, "CKID: The Center for Large-Scale Strategic Knowledge Integration and Discovery from Multiple Media," Information Sciences Institute, http://www.orau.gov/DHSSummit/2007/Presentations/Hovy.pdf, 2007.
[*A copy is attached as file:* HovyCkid.pdf]

Provides an overview of the CKID objectives and activities.

[58] I2. "i2 Analyst's Notebook: Assisted Analysis and Visualization," web page at: http://www.i2inc.com/products/analysts_notebook/, 2009.
[*A copy is attached as file:* I2 Analysts Notebook.mht]

I2 is well-established and popular among defence agencies. It provides an interactive visual environment in which to build hypotheses and view patterns, bringing information from linked databases.

[59] F. IAIS. "Visual Analytics," web page at: http://www.iais.fraunhofer.de/4801.html?&L=1, 2009. [*A copy is attached as file:* Fraunhofer IAIS.mht]

This group (under Gennady Andrienko) focuses in temporal and geospatial data, such as trajectories of moving objects, time series data, and events.

[60] *Fifth International Conference on Coordinated & Multiple Views in Exploratory Visualization* http://ieeexplore.ieee.org/xpl/tocresult.jsp?isnumber=4269933&isYear=2007, 2007.

Years before the term "visual analytics" was coined, academics were meeting at this conference to discuss this central technology of Visual Analytics..

[61] *IEEE Symposium on Visual Analytics Science and Technology 2007* http://conferences.computer.org/vast/vast2007/, 2007.
[*See file:* VAST 2007.mht]

[62] *IEEE Symposium on Visual Analytics Science and Technology 08* http://vis.computer.org/VisWeek2008/VAST/index.html, 2008.

This is the leading annual conference on Visual Analytics.

[63] *EuroVis 2009 Workshop 'Data Management & Visual Analytics'* http://www.vismaster.eu/workshop-berlin, 2009. [*See file:* EuroVis 2009 Workshop.mht]

This one-day workshop was initiated by VisMaster, to coincide with EuroVis 2009. The 10 technical papers are not yet available on-line, but the titles suggest that they are not directly relevant to Maritime Domain Awareness.

[64] IEEE, *IEEE Transactions on Visualization and Computer Graphics (TVCG)*: IEEE, http://www2.computer.org/portal/web/tvcg/, 2009.

[65] F. IGD. "Realtime Solutions for Simulation and Visual Analytics," web page at: http://www.igd.fraunhofer.de/igd-a3/index.html, 2009.

A core research topic at Fraunhofer is Visual Analytics for interactive visualization and intelligent complexity reduction, which is understood to be an interdisciplinary combination of data mining and information visualization.

[66] INRIA. "AVIZ Project-Team - Analysis and Visualization " web page at: http://www.inria.fr/saclay/research/research-teams/EqR_AVIZ/view, 2009.
[*A copy is attached as file:* AVIZ — INRIA Saclay.mht]

This is the home page for AVIZ, which is developing methods to visualize and smoothly navigate through large datasets (e.g. Wikipedia), including engineering tools for building visual analytics systems that can access, search, visualize and analyze large datasets with smooth, interactive response.

[67] *Geospatial Visual Analytics Workshop 08*, http://www.geoanalytics.net/GeoVisualAnalytics08/, 2008. [*See file:* Geospatial VA 2008.mht]

[68] International Maritime Bureau. "Live piracy Map," web page at: http://www.icc-ccs.org/index.php?option=com_fabrik&view=visualization&controller=visualization.googlemap&Itemid=219, 2009.
[*A copy is attached as file:* Live Piracy Map.mht]

A Google Maps application showing icons for pirate activity and drill-down to get details.

[69] ITT Visual Information Solutions, "Military and Intelligence Operations with ENVI " Video available on-line at: http://www.youtube.com/user/ITTVIS#play/uploads/5/FdekH5Tnrms, 2009.

[70] M. Jern, and J. Franzen, “"GeoAnalytics" - Exploring spatio-temporal and multivariate data,” in Information Visualization, 2006. IV 2006. Tenth International Conference on, 2006, pp. 25-31.

This is visual analytics, not just visualization. Jern shows how multiple linked windows can jointly display spatial and temporal information.

[71] M. Jern, L. Thygesen, and M. Brezzi, “Geovisual Analytics Web--Enabled Tools for Dissemination of OECD Regional Statistics,” in Fifth International Conference on Coordinated and Multiple Views in Exploratory Visualization (CMV 2007) Zurich, IEEE, http://www.oecd.org/dataoecd/58/25/42011526.pdf, 2007.
[*A copy is attached as file:* JernOecdExplorer.pdf]

This (draft) paper is probably th emost up-to-date description of the GAV visual analytics toolkit. GAV was used to build the “OECD eXplorer”, a customized web-compliant tool for interactively analyzing and communicating insights and discoveries about spatial-temporal and multivariate Organisation for Economic Co-operation and Development (OECD) regional data.

[72] J. Jones, R. Chang, T. Butkiewicz *et al.*, "Visualizing uncertainty for geographical information in the global terrorism database," SPIE, http://link.aip.org/link/?PSI/6983/69830E/1, http://dx.doi.org/10.1117/12.777695, 2008, pp. 69830E.
[*A copy is attached as file:* JonesUncertainty.pdf]

A serious attempt at representing uncertainty in a situation map, in this case using "Squarified treemaps." It's a tough problem and this is probably not the final solution.

[73] T. Kapler, R. Eccles, R. Harper *et al.*, "Configurable Spaces: Temporal analysis in diagrammatic contexts," in Visual Analytics Science and Technology, 2008. VAST '08. IEEE Symposium on, 2008, pp. 43-50.

"Configurable Spaces" is a new analytical method based on GeoTime for visualizing patterns of activity over time in complex diagrams. The document screen-grabs do not appear to "clarify" what is happening, and no YouTube has bene published, so it is not clear yet how successful "Configurable Spaces" is.

[74] T. Kapler, and W. Wright, "GeoTime Information Visualization," Oculus Info., http://vadl.cc.gatech.edu/documents/55_Wright_KaplerWright_GeoTime_InfoViz_Jrnl_05_send.pdf, 2005.
[*A copy is attached as file:* Wright_GeoTime_InfoViz_Jrnl.pdf]

[75] P. E. Keel, "Collaborative Visual Analytics: Inferring from the Spatial Organization and Collaborative Use of Information," in Visual Analytics Science And Technology, 2006 IEEE Symposium On, 2006, pp. 137-144.

This is a comprehensive and information-rich report on a collaboration architecture "EWall" where people engaged in the visual organization of information using graphical objects (Cards) share their work via software agents designed using psychological theories of cognitive perception of spatial object arrangements.

[76] D. A. Keim, "Information Visualization and Visual Data Mining," *IEEE Transactions on Visualization and Computer Graphics*, vol. 7, no. 1, http://fusion.cs.uni-magdeburg.de/pubs/TVCG02.pdf, 2002.
[*A copy is attached as file:* KeimVisDataMining.pdf]

Foundational paper outlining the advantages of visualization for data mining applications, and giving a long list of examples.

[77] D. A. Keim, F. Mansmann, J. Schneidewind *et al.*, "Challenges in Visual Data Analysis," in Information Visualization (IV 2006), IEEE, http://www.inf.uni-konstanz.de/cgip/bib/files/KeMaSc06.pdf, 2006, pp. 9-16.
[*A copy is attached as file:* KeimChallenges.pdf]

Provides an overview of visual analytics, its scope and concepts, and details the most important technical research challenges in the field.

[78] J. Kielman, "A Message from the Department of Homeland Security," *VAC Views*, pp. 2, February 2007, 2007.
[*A copy is attached as file:* VACViews02_feb07.pdf]

A seminal call-to-arms from a key client in the United States. Kielman lays out the challenge to deliver "designer information."

[79] J. Kohlhammer, and D. Keim, "White paper: Visual Analytics in Europe - Mastering the Information Age -," http://www.igd.fraunhofer.de/igd-a3/downloads/VA/Whitepaper_Visual_Analytics.pdf, 2007.
[*A copy is attached as file:* Kohlhammer_Whitepaper.pdf]

This whitepaper indicates that there are no European initiatives in Visual Analytics, and suggests that such initiatives be undertaken.

[80] G. Lawton, "Users Take a Close Look at Visual Analytics," *Technology News*, February 2009, 2009.
[*A copy is attached as file:* LawtonUsersCloserLook.pdf]

This article is of interest because it is one of the few that references European initiative in visual analytics.

[81] R. Lecocq, "Knowledge Mapping in Emergency Operations," DRDC Valcartier, 2009.
[*A copy is attached as file:* KMapKnowledge_mappinginEmergOps_FinalPaper6b.ppt]

KMapper provides a navigable visualization of an extended information space, including human resources, knowledge assets, procedural information, and conceptual information. These slides provide a recent update on KMapper development, and are rich in screen grabs showing the visualization strategy.

[82] H. Luo, J. Fan, D. A. Keim *et al.*, "Personalized News Video Recommendation," in Proceedings of the 15th Internation Multimedia Modeling Conference
http://viscenter.uncc.edu/TechnicalReports/CVC-UNCC-09-18.pdf, 2009.
[*A copy is attached as file:* LuoNewsVideo.pdf]

Analyses large-scale collections of multi-model news videos to provide interactive navigation and exploration at the topic level. Users can build up their mental models of news needs precisely and formulate their queries easily by directly selecting the visible news topics on the topic network.

[83] R. Maciejewski, S. Rudolph, G. Tebbetts *et al.*, "Contextualizing Syndromic Hotspots - A Visual Analytics Approach," in Geospatial Visual Analytics, Uta,
http://www.geoanalytics.net/GeoVisualAnalytics08/a03.pdf, 2008.
[*A copy is attached as file:* Maciejewski_Syndromic_Hotspots.pdf]

This visualization of spatially-distributed features ("syndromic hot-spot" in this example, but could be "gale" in the RMP) and displaying them as changing in time, may be relevant to the time-varying situational picture.

[84] F. Mansmann, L. Meier, and D. A. Keim, "Visualization of Host Behavior for Network Security," in Workshop on Visualization for Computer Security, Sacramento, IEEE, http://infovis.uni-konstanz.de/papers/2008/vizsec2007.pdf, 2007.
[*A copy is attached as file:* Mansmann_HostNetSecurity.pdf]

[85] M. Matthews, L. Rehak, J. Famewo *et al.*, "Evaluation of New Visualization Approaches for Representing Uncertainty in the Recognized Maritime Picture," DRDC Atlantic CR 2008-177, DRDC Atlantic, 2008.
[*A copy is attached as file:* MatthewsUncertainty.pdf]

This DRDC study focuses on representing uncertainty and swath coverage in the Maritime Picture. It includes a literature review, user interface brainstorming, protoyping of some designs, and tests with CF analysts.

[86] R. May, P. K. Arya, D. A. Bowman *et al.*, "Challenges to Applying Virtual Reality Technology and Techniques to Visual Analytics," in Virtual Reality Conference, 2006, 2006, pp. 303-306.

A panel discussion to introduce the domain of visual analytics to the virtual reality (VR) and artificial reality (AR) audience and explore how and where VR/AR research can be adapted for use in visual analytics.

[87] S. Mehta, S. Parthasarathy, and R. Machiraju, "Visual Exploration of Spatio-temporal Relationships for Scientific Data," in IEEE Visual Analytics Science and Technology (VAST 06), ftp://ftp.cse.ohio-state.edu/pub/tech-report/2006/TR33.pdf, 2006.
[*A copy is attached as file:* Mehta_Spatio-Temporal Relat.pdf]

Mostly useful for analysis of periodic motion. Not very rich in either visualization or support for analysis.

[88] L. Meier. "Visualization of Network Time Series," web page at: http://graphics.uni-konstanz.de/bw-fit/projekte/projekt7.php, 2008.
[*A copy is attached as file:* MeierNetworkTimeSeries.mht]

A lab web page (in German) focused on visualizing network behaviour (e.g, load profiles, port information, IP packet information, etc.) as a function of time. The specific challenges are in the extremely large data sets and the high degree of detail required.

[89] B. S. Meiguins, and A. S. G. Meiguins, "Multiple coordinated views supporting visual analytics," in SIGKDD Workshop on Visual Analytics and Knowledge Discovery: Integrating Automated Analysis with Interactive Exploration, Paris, France, ACM, http://www.hiit.fi/vakd09/vakd09meiguins.pdf, 2009, pp. 40-45.
[*A copy is attached as file:* MeiguinsMultiCoordViews.pdf]

Uses their Java tool PRISMA to analyse the IEEE VAST 2008 contest data. Coordination between views is based on filters, colour, shape, and size, plus support for details-on-demand. It appears that the interface was very customized for this challenge.

[90] D. Mewett, and D. Clark, "Dynamic Display for Visualising Surveillance Coverage in Complex Terrain," in DSTO External Publications, DSTO, http://www.siaa.asn.au/get/2411853305.pdf, 2004.
[*A copy is attached as file:* MewettSurvCovg.pdf]

This is one of very few papers that looks at visualization of sensor coverage patterns over time. The authors implemented a solution in which coverage areas fade with time, to indicate that the data is stale.

[91] MIAS. "Center for Multimodal Information Access and Synthesis Center," web page at: http://mias.uiuc.edu/, 2009.
[*A copy is attached as file:* MiasHomePage.mht]

Web page for MIAS, giving links to faculty and projects.

[92] National Visualization and Analytics Center. "NVAC Call for Internships & Fellowships," 2009. [*A copy is attached as file:* NVAC Call For Interns.mht]

This web page provides a good quick overview of what NVAC does.

[93] National Visualization and Analytics Center, *VAC Views*, nvac.pnl.gov/vacviews, 2009.
[*See file:* VACViews06_may09.pdf]

VAC Views is the only publication dedicated to Visual Analytics. It is a magazine rather than a scholarly journal, but provides good insights into activities around the VAC Consortium.

[94] NEVAC, "North-East Visualization and Analytics Center " available on-line at: http://www.geovista.psu.edu/NEVAC/, 2009.
[*A copy is attached as file:* NEVAC Penn State University.mht]

[95] NVAC. "National Visualization and Analytics Center Research and Development," web page at: http://nvac.pnl.gov/research.stm, 2009.
[*A copy is attached as file:* NvacResearch.mht]

The NVAC continues to a lot of in-house research and the Pacific Northwest National Lab, as summarized and linked here.

[96] NVAC. "Visualization & Analytics Centers (VAC) Consortium," web page at: http://nvac.pnl.gov/consortium.stm, 2009.
[*A copy is attached as file:* VAC Consortium.mht]

The VA consortium includes both users and producers of VA tools. It provides value to its members and to DHS, by giving valuable insight into the activities of groups within the NVAC program and by influencing the direction future generations of visual analytics. This website gives links to information pages about all previous VAC consortium meetings.

[97] Oculus. "GeoTime: Efficient Insight into Behaviors in Time and Space," web page at: http://www.oculusinfo.com/SoftwareProducts/GeoTime.html, 2009.
[*A copy is attached as file:* Oculus - GeoTime.mht]

[98] Pacific Northwest National Laboratory (PNNL), "In-Spire Tips and Techniques "At a Glance" Version 3.0," http://in-spire.pnl.gov/TipsandTechniques30.pdf, 2005.
[*A copy is attached as file:* InSpireTips.pdf]

This is an excellent introduction to how In-Spire works, including a careful description of how analysis can progress from one visualization to another. It shows examples of all the major screens.

[99] Pacific Northwest National Laboratory (PNNL). "Assessment Wall," web page at: http://infoviz.pnl.gov/tech_assessment.stm, 2008.
[*A copy is attached as file:* Assessment Wall.mht]

This is designed to help users more easily monitor and explore continually updating text sources such as news or reports, through a high-resolution touch-screen interface.

[100] Pacific Northwest National Laboratory (PNNL), "In-Spire Visual Document Analysis," Youtube available on-line at: http://www.youtube.com/watch?v=7bIRmJlhjbQ&feature=channel_page, 2009.
[*A copy is attached as file:* Youtube_InSpire.mht]

This Youtube video marketing pitch is less informative than the Starlight youtube, bur still of interest because it shows the tool at work, and gives ideas of possible applications.

[101] Pacific Northwest National Laboratory (PNNL), "Starlight Information Visualization System," YouTube video available on-line at: http://www.youtube.com/watch?v=3rV62mVFMx8&feature=channel_page, 2009.
[*A copy is attached as file:* YouTube - Starlight.mht]

Although this YouTube video only touches the surface of what Starlight can do, it is valuable because it shows the dynamics of some of the visualization - something that cannot be inferred from static publications.

[102] Palgrave McMillan Ltd., *Information Visualization*, http://www.palgrave-journals.com/ivs/index.html, 2009.

This journal is newer and less well-known than the IEEE journal, but is being supported by leading visual analytics researchers such as John Stasco.

[103] A. Perer, and B. Shneiderman, "Integrating Statistics and Visualization for Exploratory Power: From Long-Term Case Studies to Design Guidelines," *IEEE Computer Graphics and Applications*, pp. 39-51, http://www.computer.org/portal/cms_docs_cga/cga/content/cga_per_3_09.pdf, 2009.
[*A copy is attached as file:* Perer_EvaluatingVA_2009.pdf]

A useful magazine article in which the links between data mining and visual analytics are developed.

[104] Purdue University. "Purdue University Regional Visualization and Analytics Center," web page at: https://engineering.purdue.edu/PURVAC/pdf_fliers/PURVAC01_Overview.pdf, 2009.
[*A copy is attached as file:* PURVAC01_Overview.pdf]

PURVAC is researching: data integration, Effective Analysis of Anonymized Data, Disaster Response Life Cycle, Mobile Analytics for Command & Control and Emergency Response, Personnel Tracking and Video Capture For Emergency Response, Sensor-Driven Video Analytics, Social Networks, Zoonotic Disease Spread, Time-Space Modeling and Analysis for Disease Surveillance, and Network Flow Monitoring and Forensics

[105] W. Renaud, and A. Isenor, "Situational Awareness: Inspiring Operational Clarity," *Canadian Military Journal* vol. 10, no. 4, Winter, 2009.
[*A copy is attached as file:* RenaudSituAware.pdf]

This is Cdr Renaud's "manifesto" for situational awareness, and thus a very helpful window into CF thinking and planning for Maritime Awareness.

[106] M. Riveiro, “Evaluation of uncertainty visualization techniques for information fusion,” in Information Fusion, 2007 10th International Conference on, 2007, pp. 1-8.

Looks at uncertainty representations in a number of fields, from graphical rendering to surveillance displays, but does not come up with definitive recommendations about how it should be done.

[107] M. Riveiro, G. Falkman, T. Ziemke *et al.*, “Reasoning about anomalies: a study of the analytical process of detecting and identifying anomalous behavior in maritime traffic data,” in Proc. of SPIE Vol. 7346, 73460A SPIE, http://spie.org//app/program/index.cfm?fuseaction=conferencedetail&confid=869287, 2009.

Riveiro reports on observations of maritime surveillance operators looking for anomalies,and outlines a 3-step surveillance process, which she compares to "overview, zoom, details on demand," and to the foraging loop. A key observation is that there is always a "wait" step, while the analysts clarify what the motion is, etc.

[108] M. Riveiro, G. Falkman, T. Ziemke *et al.*, “VISAD: an interactive and visual analytical tool for the detection of behavioral anomalies in maritime traffic data,” in Visual Analytics for Homeland Defense and Security, SPIE, http://spiedigitallibrary.aip.org/getpdf/servlet/GetPDFServlet?filetype=pdf&id=PSISDG007346000001734607000001&idtype=cvips&prog=normal, 2009.
[*A copy is attached as file:* RiveiroVisad.pdf]

This is a maritime anomaly detection system that preprocesses the maritime reports in order to highlight potential anomalies, then offers the operator a screen that describes the ship (though it gives no obvious description of why it was flagged as an anomaly). It is not clear from the paper whether VISAD helps the operator to build a visual analysis of the vessels - VISAD may just be a visualization system..

[109] M. Riveiro, G. o. Falkman, and T. Ziemke, “Visual Analytics for the Detection of Anomalous Maritime Behavior,” in 12th International Conference Information Visualisation, IEEE, 2008.
[*A copy is attached as file:* Riveiro_VaAnomMaritime.pdf]

Describes a system that supports the acquisition of situation awareness with user involvement in the anomaly detection process using two layers of interactive visualizations. An interactive data mining module supports the insertion of the user’s knowledge and experience. The visual language used in this prototype is in some cases a poor match to the domain.

[110] J. C. Roberts, “State of the Art: Coordinated & Multiple Views in Exploratory Visualization,” in Coordinated & Multiple Views in Exploratory Visualization (CMV 07) Zurich, IEEE, http://people.cs.ubc.ca/~tmm/courses/533/readings/cmvsurvey.pdf, 2007.
[*A copy is attached as file:* RobertsCmvSurvey.pdf]

Gives an overview of Coordinated and Multiple Views research, which is a core component of many Visual Analytics products.

[111] A. C. Robinson, “Collaborative synthesis of visual analytic results,” in Visual Analytics Science and Technology, 2008. VAST '08. IEEE Symposium on, 2008, pp. 67-74.

Robinson ran experiments to watch how people collaborate, and then built an architect to support the various approaches that they used.

[112] T. Rowland, "Spies Look to Second Life and Think Time Machine!," *Got Game*, news.gotgame.com/.../1281/, 2008.

[113] J. Roy, “Anomaly detection in the maritime domain,” in Optics and Photonics in Global Homeland Security IV, SPIE, 2008.

[114] SAIC. "SAIC: Future Point Systems and the Starlight Visual Information System," web page at: http://www.saic.com/contractcenter/gsa-it/futurepoint.html, 2009.

Mainly of interest because of the pricing information on Starlight.

[115] San Diego State University, "3D Touch Table in ESRI 2005 User Conference," available on-line at: http://www.youtube.com/watch?v=W3dz2xpCJVU, 2005.
[*A copy is attached as file:* 3DTouchTable.avi]

This is a video of the 3D touch table in action.

[116] T. Schreck, J. Bernard, T. Tekusová *et al.*, “Visual cluster analysis of trajectory data with interactive Kohonen maps,” in IEEE Symposium on Visual Analytics Science and Technology 08, Columbus, IEEE, http://www.gris.informatik.tu-darmstadt.de/~tschreck/papers/vast08.pdf, 2008.
[*A copy is attached as file:* Schreck Trajectories.pdf]

To simplify the RMP it may be helpful to find common patterns in the shapes of ship tracks, using an automated tool to indicate whether two tracks have a similar shape. This paper looks at using a self-organizing map for that purpose. This research uses Visual Analytics to help guide the self-organizing map to create the tool.

[117] *Visualization, Analytics & Spatial Decision Support* 2006.

No relevant papers for Maritime Awareness were found in this workshop.

[118] B. Shneiderman, “The eyes have it: a task by datatype taxonomy for information visualization,” in IEEE Symposium on Visual Languages, IEEE Computer Society Press, hhttps://eprints.kfupm.edu.sa/69898/1/69898.pdf, 1996, pp. 336–343.
[*A copy is attached as file:* SchneidermanEyesHaveIt.pdf]

This is a seminal paper by Schneiderman laying out a very practical taxonomy of visualization strategies and domains. Not explicitly Visual Analytics, but an important foundation for it.

[119] Sifer, “User Interfaces for the Exploration of Hierarchical Multi-dimensional Data,” in IEEE Symposium On Visual Analytics And Technology, Baltimore, IEEE, http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1304&context=commpapers, 2006, pp. 175-182.
[*A copy is attached as file:* SiferHier.pdf]

Defines metrics to compare interfaces for interactive exploration of hierarchical multi-dimensional data, and uses those metrics to evaluate various visualization strategies

[120] Sofrelog. "Sofrelog the leader in radar processing technology," web page at: http://www.sofrelog.com/main_index.htm, 2008.
[*A copy is attached as file:* Sofrelog.mht]

[121] *Visual Analytics for Homeland Defense and Security (Conference 7346) in Defense, Security, & Sensing*, http://spie.org//app/program/index.cfm?fuseaction=conferencedetail&confid=869287, 2009.
[*See file:* SpieConferenceDetail.mht]

Only one relevant paper was found from this small session in the annual SPIE conference.

[122] Stanford. "Stanford vis Group," web page at: http://vis.stanford.edu/, 2009.
[*A copy is attached as file:* Visualization at Stanford University.mht]

This is a page of links to the Stanford visualization and visual analytics pages.

[123] J. Stasco. "Information Interfaces Group," web page at: http://www.cc.gatech.edu/gvu/ii/, 2009.
[*A copy is attached as file:* GeorgiaTech.mht]

This is the home page for John Stasco's lab at Georgia Tech.

[124] J. Stasko, C. Görg, and Z. Liu, "Jigsaw: supporting investigative analysis through interactive visualization," *Information Visualization*, vol. 7, pp. 118-132, http://www.palgrave-journals.com/ivs/journal/v7/n2/pdf/9500180a.pdf, 2008.
[*A copy is attached as file:* StascoJigsaw.pdf]

A good journal article describing Jigsaw, including a frank discussion of some of its limitations (e.g. Jigsaw does not provide overviews that help an analyst find something interesting to start looking at.

[125] J. Stasko, C. Gorg, Z. Liu *et al.*, "Jigsaw - Visual Analytics," Youtube available on-line at: http://www.youtube.com/user/cagoe, 2008.
[*A copy is attached as file:* jigsaw_video.avi]

[126] B. Suh, E. H. Chi, B. A. Pendleton *et al.*, "Us vs. Them: Understanding Social Dynamics in Wikipedia with Revert Graph Visualizations," in IEEE Symposium on Visual Analytics Science and Technology 2007 Sacramento, IEEE, http://www.citeulike.org/user/vulpeto/article/2359769, 2007.

Show how visualization and visual analytics can provide important insights into Wiki-type collaborative knowledge bases (such as Intellipedia for example).

[127] Thetus, "The Thetus Intelligence Fusion Platform," Thetus Inc., http://fusion.thetus.com/docs/Thetus_Intel_Fusion.pdf, 2007.
[*A copy is attached as file:* Thetus_Intel_Fusion.pdf]

The Thetus Intelligence Fusion Platform seems to resemble Analyst's Notebook, but gives more visibility to an underlying "Knowledge Base" in the form of an ontology that acts as a repository for the emerging "story" that is built up by the analyst.

[128] Thetus. "Thetus Knowledge Services," web page at: http://www.thetus.com/index.html, 2008.
[*A copy is attached as file:* Thetus Thetus Knowledge Services.mht]

Thetus started out hoping to be like i2, only with more intelligence; more real fusion. Now they seem to have given up on marketing to the police and military. They are big on semantic modelling and tracking meaning and provenance of information.

[129] J. Thomas, "Taxonomy for Visual Analytics: Seeking Feedback," *VAC Views*, pp. 6-7, May 2009, 2009.
[*A copy is attached as file:* VACViews06_may09.pdf]

This is a typology of Visual Analytics domains, goals, data types, and technologies, offered by Jim Thomas as a discussion point.

[130] J. J. Thomas, "Visual Analytics Techniques that Enable Knowledge Discovery: Detect the Expected and Discover the Unexpected," Director, National Visualization and Analytics Center, http://www.hiit.fi/vakd09/vakd09thomas-slides.pdf, 2009.
[*A copy is attached as file:* ThomasVakd09-slides.pdf]

Slides that provide a brief overview of Visual Analytics from the guru himself. The first part of the presentation is a useful discussion of what is (and is not) Visual Analytics.

[131] Author ed.eds., "Illuminating the Path," IEEE, http://nvac.pnl.gov/agenda.stm#book, 2005, p.pp. Pages.
[*See file:* IlluminatingThePath_Thomas.pdf]

This is the key foundational reference that originally set the agenda for Visual Analytics development, and continues to be very influential.

[132] University of Konstanz. "VisMaster," web page at: http://www.vismaster.eu/node/2, 2008.
[*A copy is attached as file:* VisMaster.mht]

This is the homepage for VisMaster, a European attempt to coordinate some visual analytics research initiatives. The website was created in October 2008, but the last news update on the page was March 12, 2009. A scan of the website links for 5 of the 17 "VisMaster Partner" agencies revealed none of the websites carried the words "VisMaster" or "Analytics."

[133] University of Konstanz. "Chair for Databases, Data Analysis and Visualization " web page at: http://www.informatik.uni-konstanz.de/en/arbeitsgruppen/infovis/, 2009.
[*A copy is attached as file:* UKonstanz Data Analysis and Visualization.mht]

This lab (under Daniel Keim) focuses on techniques for interactive mass data analysis for very large multidimensional and geographic data sets, clustering methods and index structures for high-dimensional spaces, and multimedia similarity search (2D and 3D). Note that the home page never mentions visual analytics, so this may just be visualization.

[134] University of Washington. "Pacific Rim Visualization and Analytics Center (PARVAC)," web page at: http://parvac.washington.edu/index.php, 2009.
[*A copy is attached as file:* PARVAC for Area Maritime Security.mht]

PARVAC plans to develop: a map of the sense-making, decision-making and coordination processes of the diverse Area Maritime Security community, both during non-crisis and crisis situations; an evolving map of technology components that support these AMS processes, such as command and control (C2) systems, analysis tools, and databases; and a visual representation of how existing technology and possible analytic and coordination enhancements map to these regional safety and security processes.

[135] UNOSAT. "Pirate Attack Density in the Gulf of Aden " web page at: http://unosat.web.cern.ch/unosat/freeproducts/somalia/Piracy/UNOSAT_SO_PirateDensity_Nov08_Highres_v1.pdf, 2008.
[*A copy is attached as file:* UNOSAT_PirateDensity_Nov08.pdf]

Illustrates a number of visualization strategies for visual data mining of maritime events. (UNOSAT is UN Institute for Training and Research (UNITAR) Operational Satellite Applications Programme)

[136] R. Vernik, G. S. Von Itzstein, and A. Bouchard, “Imago: An integrated prototyping, evaluation and transitioning environment for information visualisation,” in Information Visualization, 2007. IV '07. 11th International Conference, 2007, pp. 17-22.
[*A copy is attached as file:* VernikImago.pdf]

Imago is a distributed environment that supports visualization, and thus a candidate for hosting collaborative visual analytics.

[137] Visual Analytics Inc. "Home Page," web page at: http://www.visuala.com/index.cfm, 2009.
[*A copy is attached as file:* Visual Analytics Inc.mht]

Visual Analytics Inc. has literally had the copyright on the term "Visual Analytics" since 1998. They consult to Homeland Defence and security agencies, but a lot of their business is with financial and market analytics. They sponsor VisuaLinks and Digital Information Gateway tools.

[138] Visual Analytics Inc. "VisuaLinks - The Pattern Discovery Software," web page at: http://www.visualinks.com/, 2009.

Visualinks seems to be similar to I2, accessing databases, searching for implicit relationships, and displaying them visually.

[139] C. Weaver, “Is Coordination a Means to Collaboration?,” in International Conference on Coordinated & Multiple Views in Exploratory Visualization (CMV 07), Zürich, SZ, IEEE, http://www.cs.ou.edu/~weaver/academic/publications/weaver-2007c.pdf, 2007.

Explores how collaboration can be achieved by giving separate users coordinated and linked views of the analysis space, and giving managers tools to "metavisualize" the data.

[140] L. Wilkinson, A. Anand, and R. Grossman, "High-Dimensional Visual Analytics: Interactive Exploration Guided by Pairwise Views of Point Distributions," *IEEE Transactions in Visualization and Computer Graphics*, vol. 12, no. 6, pp. 1363-1372, Nov/Dec 2006, http://www.cs.uic.edu/~wilkinson/Publications/sorting.pdf, 2006.
[*A copy is attached as file:* WilkinsonHighDimensionalVA.pdf]

A detailed look at finding patterns in very high-dimensional data, using statistical transformations to re-project the data and thus reveal the patterns, and plots that link large numbers of two-dimensional views (usually scatter plots) of the data.

[141] N. Willems, H. van de Wetering, J. van Wijk *et al.*, "Visualization of vessel trajectories for maritime safety and security systems," in IEEE Symposium on Visual Analytics Science and Technology (VAST 08), Columbus, Ohio, IEEE, http://www.esi.nl/projects/poseidon/publications/InteractivePosterVisualization_Willems.pdf, 2008.
[*A copy is attached as file:* Willems_Vis_Traject2.pdf and Willems_Vis_Traject.pdf]

Looks at a very specific graphical strategy for visualizing track patterns in a very busy part of the North Sea, using AIS data. Tracks are interpolated and convolved with a kernel in such a way that the accumulated view represent ship density, rather than number of tracks. (10 slow-moving ships are more dense than 15 fast-moving ships).

[142] N. Willems, H. van de Wetering, J. van Wijk *et al.*, "Visualization of vessel movements " in 11th Eurographics/IEEE-VGTC Symposium on Visualization (Computer Graphics Forum; Proceedings of EuroVis 2009), 2009 IEEE, http://www.win.tue.nl/~cwillems/public/eurovis09.pdf, 2009.
[*A copy is attached as file:* Willems_Vis_Traject3.pdf]

This paper follows-up publications by Willems in 2008, showing how to visualize aggregated vessel trajectories. The result is a nice, clear indication of both individual tracks and time-averaged track.

[143] W. Wright, and T. Kapler, "Visualization of Blue Forces Using Blobology," in Command and Control Research and Technology Symposium,, http://www.dodccrp.org/events/2002_CCRTS/Tracks/pdf/029.PDF, 2002.
[*A copy is attached as file:* wrightBlobology2002.pdf]

Blobology provides a way to represent a distributed group of individuals, including the time-evolution of the shape and location of that group.

[144] Z. Xie, S. Huang, M. O. Ward *et al.*, "Exploratory Visualization of Multivariate Data with Variable Quality," in Visual Analytics Science and Technology (VAST 06), IEEE, http://davis.wpi.edu/~xmdv/docs/vast06_dataqua.pdf, 2006.
[*A copy is attached as file:* XieVisualizeQuality.pdf]

An analysis of various ways to visually reveal errors or data quality problems in individual numbers, whole records, or data sources.

[145] F. Yang, H. Goodell, R. Pickett *et al.*, "Data Exploration Combining Kinetic and Static Visualization Displays," in Proceedings of the Fourth International Conference on Coordinated & Multiple Views in Exploratory Visualization (CMV'06), IEEE, http://www2.computer.org/portal/web/csdl/proceedings/cc#5, 2006.

Describes ideas for showing motion in a static display, but mainly for fields of moving things.

[146] J. Yue, A. Raja, D. Liu *et al.*, "A Blackboard-based Approach towards Predictive Analytics," in Symposium on Technosocial Predictive Analytics, Stanford University, AAAI, http://www.viscenter.uncc.edu/TechnicalReports/CVC-UNCC-08-36.pdf, 2009.
[*A copy is attached as file:* YuePredictive.pdf]

This is an important paper about predictive analytics - the use of visual analytics for predicting what may happen.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified.)

1. ORIGINATOR (Name and address of the organization preparing the document.)

MacDonald Dettwiler and Associates Ltd /
Salience Analytics Inc.
13800 Commerce Parkway
Richmond BC, Canada
V6V 2J3

2. SECURITY CLASSIFICATION
(Overall security classification of the document, including special warning terms if applicable.)

Unclassified

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Literature and Product Review of Visual Analytics for Maritime Awareness (U)

4. AUTHORS (Last name, followed by initials – ranks, titles, etc. not to be used.)

Davenport, M.

5. DATE OF PUBLICATION (month and year of publication of document.)

October 28, 2009

6. NO. OF PAGES (Including Annexes, Appendices and DCD sheet.)

102

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

11hm

8b. CONTRACT NO. (If appropriate, the applicable number under which the document was written)

W7701-9-2075/NP

9a. ORIGINATOR'S DOCUMENT NUMBER (Official document number by which the document is identified by the originating activity. Number must be unique to this document.)

DRDC Valcartier CR 2009-228

9b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned to this document either by the originator or the sponsor.)

10. DOCUMENT AVAILABILITY (Any limitation on further distribution of the document, other than those imposed by security classification.)

(x) Unlimited distribution
( ) Distribution limited to defence departments
( ) Distribution limited to defence contractors
( ) Distribution limited to government
( ) Distribution limited to Defence R&D Canada
( ) Controlled by Source

11. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (10). However, where further distribution (beyond the audience specified in (10) is possible, a wider announcement audience may be selected.)

Unlimited

12. ABSTRACT (Brief and factual summary of the document. May also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). May be in English only).

This is a study of the state-of-the-art in Visual Analytics (VA) technologies that might support the maintenance of the Recognized Maritime Picture (RMP). It begins with an analysis of the term "Visual Analytics," including what qualifies and does not qualify under that term, and proposes a 4-point checklist of required elements. It reviews what interaction patterns are typical in VA and what topics need to be visualized for the RMP, and thus establishes a list of required tool capabilities. Links are then provided to approximately 70 papers that address these requirements. Global VA researchers, research groups, journals, and conferences are summarized. Fifteen VA products that are particularly relevant to the identified requirements are tabulated. An annotated bibliography, attached as an appendix, lists and provides an educated assessment of 146 relevant papers, websites, and product brochures.

Ceci est une étude de l'état de l'art des technologies d'Analytique Visuelle (AV) qui seraient susceptibles de soutenir la mise à jour du Tableau de la Situation Maritime (TSM). Elle débute avec une analyse du terme « Analytique Visuelle », incluant ce qui se qualifie et ne se qualifie pas sous cette définition, et propose une liste de contrôle de quatre points des éléments requis. Elle passe en revue les modèles d'interaction typiques en AV et les sujets qui doivent être visualisés pour le TSM et établit ainsi une liste des fonctionnalités requises pour l'outil. Ensuite, des liens vers environ 70 articles qui adressent ces exigences sont fournis. Un résumé des chercheurs en AV, des groupes de recherche, des journaux et des conférences est aussi donné. Quinze produits d'Analytique Visuelle qui sont particulièrement pertinents en regard des exigences identifiées sont colligés. Finalement, une bibliographie annotée énumérant et fournissant une évaluation de 146 articles, sites internet et brochures de produits se trouve en annexe.

13. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases characterizing a document and could be helpful in cataloguing it. Should be **Unclassified** text. If not , the classification of each term should be indicated as with the title. Equipment model designation, trade name, military project code name, and geographic location may be included. If possible, should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified.)

Visual Analytics, Domain Awareness, Maritime, Recognized Maritime Picture, Data Mining, Situation Awareness, Visualization, Collaboration, Sensor Coverage, Bibliography

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified.)

1. ORIGINATOR (Name and address of the organization preparing the document.)

MacDonald Dettwiler and Associates Ltd /
Salience Analytics Inc.
13800 Commerce Parkway
Richmond BC, Canada
V6V 2J3

2. SECURITY CLASSIFICATION
(Overall security classification of the document, including special warning terms if applicable.)

Unclassified

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Literature and Product Review of Visual Analytics for Maritime Awareness (U)

4. AUTHORS (Last name, followed by initials – ranks, titles, etc. not to be used.)

Davenport, M.

5. DATE OF PUBLICATION (month and year of publication of document.)

October 28, 2009

6. NO. OF PAGES (Including Annexes, Appendices and DCD sheet.)

102

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

11hm

8b. CONTRACT NO. (If appropriate, the applicable number under which the document was written)

W7701-9-2075/NP

9a. ORIGINATOR'S DOCUMENT NUMBER (Official document number by which the document is identified by the originating activity. Number must be unique to this document.)

DRDC Valcartier CR 2009-228

9b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned to this document either by the originator or the sponsor.)

10. DOCUMENT AVAILABILITY (Any limitation on further distribution of the document, other than those imposed by security classification.)

(x) Unlimited distribution
( ) Distribution limited to defence departments
( ) Distribution limited to defence contractors
( ) Distribution limited to government
( ) Distribution limited to Defence R&D Canada
( ) Controlled by Source

11. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (10). However, where further distribution (beyond the audience specified in (10) is possible, a wider announcement audience may be selected.)

Unlimited

12. ABSTRACT (Brief and factual summary of the document. May also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). May be in English only).

This is a study of the state-of-the-art in Visual Analytics (VA) technologies that might support the maintenance of the Recognized Maritime Picture (RMP). It begins with an analysis of the term "Visual Analytics," including what qualifies and does not qualify under that term, and proposes a 4-point checklist of required elements. It reviews what interaction patterns are typical in VA and what topics need to be visualized for the RMP, and thus establishes a list of required tool capabilities. Links are then provided to approximately 70 papers that address these requirements. Global VA researchers, research groups, journals, and conferences are summarized. Fifteen VA products that are particularly relevant to the identified requirements are tabulated. An annotated bibliography, attached as an appendix, lists and provides an educated assessment of 146 relevant papers, websites, and product brochures.

Ceci est une étude de l'état de l'art des technologies d'Analytique Visuelle (AV) qui seraient susceptibles de soutenir la mise à jour du Tableau de la Situation Maritime (TSM). Elle débute avec une analyse du terme « Analytique Visuelle », incluant ce qui se qualifie et ne se qualifie pas sous cette définition, et propose une liste de contrôle de quatre points des éléments requis. Elle passe en revue les modèles d'interaction typiques en AV et les sujets qui doivent être visualisés pour le TSM et établit ainsi une liste des fonctionnalités requises pour l'outil. Ensuite, des liens vers environ 70 articles qui adressent ces exigences sont fournis. Un résumé des chercheurs en AV, des groupes de recherche, des journaux et des conférences est aussi donné. Quinze produits d'Analytique Visuelle qui sont particulièrement pertinents en regard des exigences identifiées sont colligés. Finalement, une bibliographie annotée énumérant et fournissant une évaluation de 146 articles, sites internet et brochures de produits se trouve en annexe.

13. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases characterizing a document and could be helpful in cataloguing it. Should be **Unclassified** text. If not , the classification of each term should be indicated as with the title. Equipment model designation, trade name, military project code name, and geographic location may be included. If possible, should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified.)

Visual Analytics, Domain Awareness, Maritime, Recognized Maritime Picture, Data Mining, Situation Awareness, Visualization, Collaboration, Sensor Coverage, Bibliography

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

www.drdc-rddc.gc.ca